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# HackSpace

TECHNOLOGY IN YOUR HANDS

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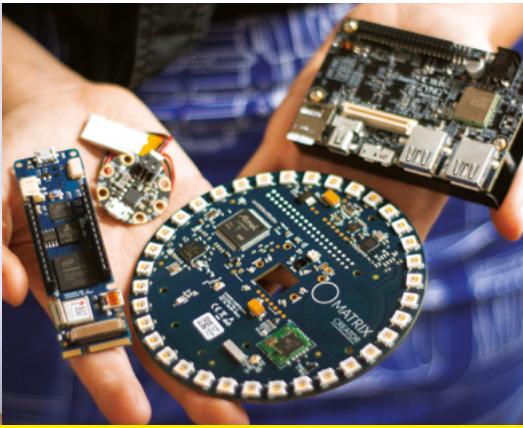
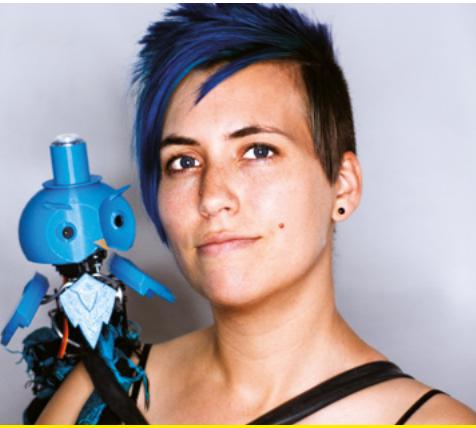
October 2018

Issue #11

Oct 2018  
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## BEST MAKER HARDWARE

Alex Glow's guide to the year's finest hackable technology

ALSO INSIDE

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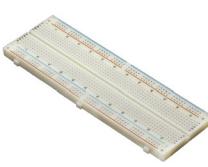
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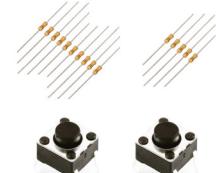


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# Welcome to HackSpace magazine

Any hardware is hackable if you're determined enough – and there are plenty of determined hackers out there – but the right hardware can make it much easier to focus on getting your makes to do what you want, rather than wrangling with bits and bytes. This issue, we're taking a look at technology that's designed to make our lives easier, and we're bringing you the best new maker technology to help make your builds easier. Microcontrollers, field-programmable gate arrays, fabrication machines, and more come under scrutiny.

**This issue, we're taking a look at technology that's designed to make our lives easier, and we're bringing you the best new maker technology to help make your builds easier**

up to you, but we're really inspired by Martin Mander's work giving older hardware a new lease of life (see page 18), and we're tempted to start work on our own Hacky Racer (see page 48). But, that's just us. What are you going to build? We'd love to find out. Let us know on Twitter: **@HackSpaceMag**, or via our website at **hsmag.cc/hello**.

**Got a comment, question or thought about HackSpace magazine?**

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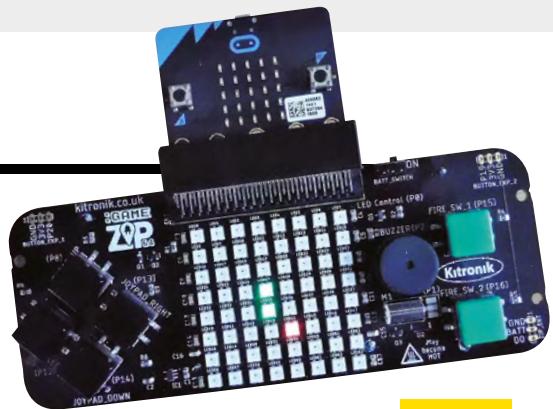
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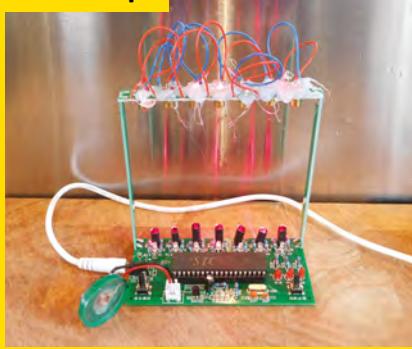
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Some of the tools and techniques shown in HackSpace Magazine are dangerous unless used with skill, experience and appropriate personal protection equipment. While we attempt to guide the reader, ultimately you are responsible for your own safety and understanding the limits of yourself and your equipment. HackSpace Magazine is intended for an adult audience and some projects may be dangerous for children. Raspberry Pi (Trading) Ltd does not accept responsibility for any injuries, damage to equipment, or costs incurred from projects, tutorials or suggestions in HackSpace Magazine. Laws and regulations covering many of the topics in HackSpace Magazine are different between countries, and are always subject to change. You are responsible for understanding the requirements in your jurisdiction and ensuring that you comply with them. Some manufacturers place limits on the use of their hardware which some projects or suggestions in HackSpace Magazine may go beyond. It is your responsibility to understand the manufacturer's limits.



# Arduino watch

By Electronoobs

 [electronoobs.com](http://electronoobs.com)

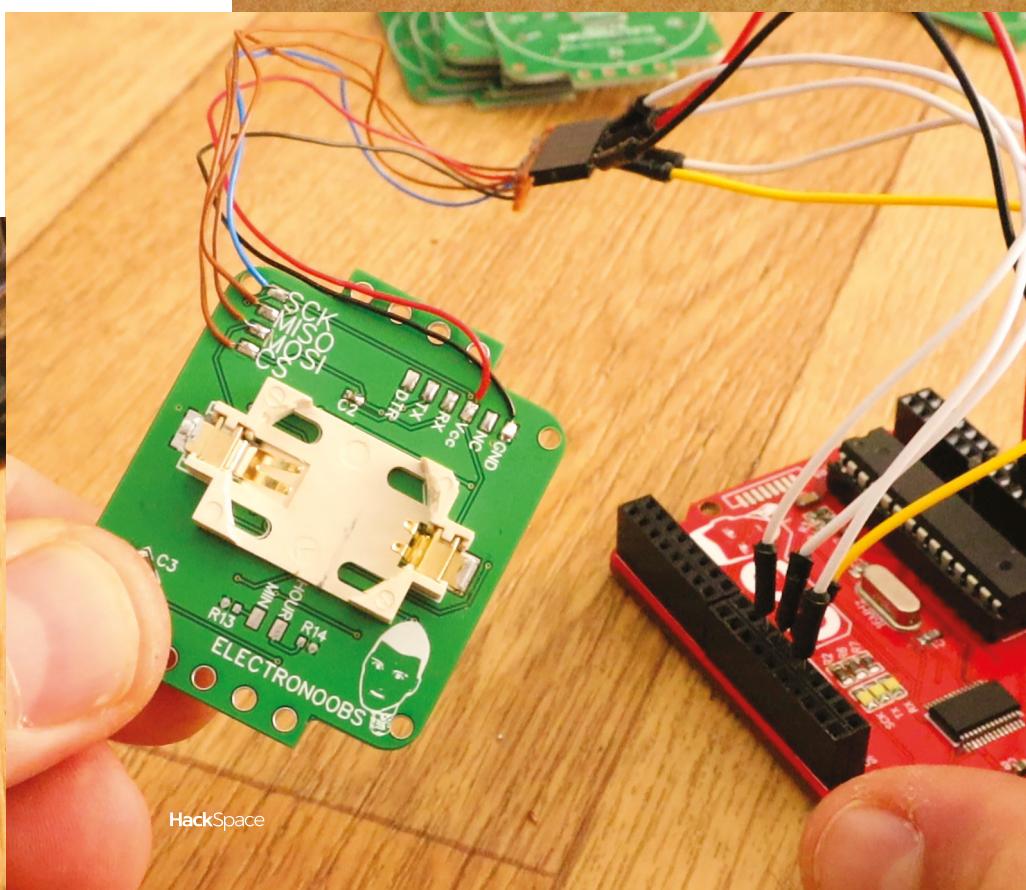
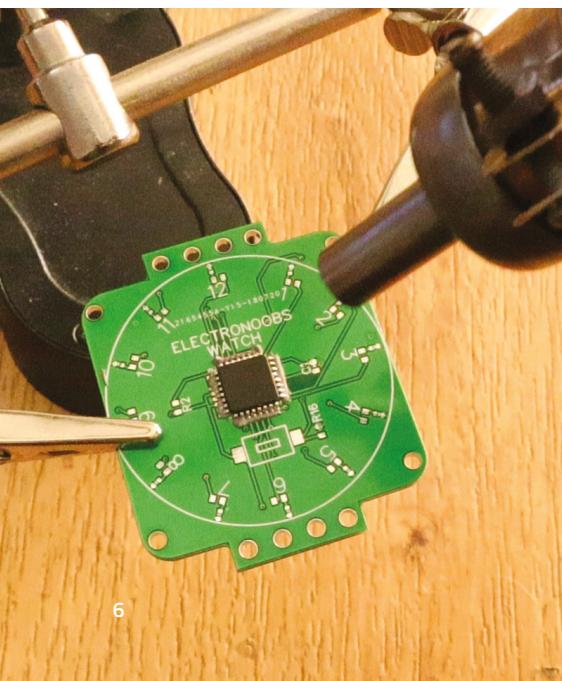
I'm a 25-year-old electronics engineer. I have my own YouTube channel where I teach simple tutorials on electronics, programming, 3D printing, radio control, and basic electromagnetism. The idea of this watch was to teach how the ATmega328 chip works without a crystal, so using the internal clock of 8MHz that it has. I show how to do that by burning the new bootloader to the chip. Also, this project is about low power, so I also demonstrate how to use the sleep functions for the Arduino code.

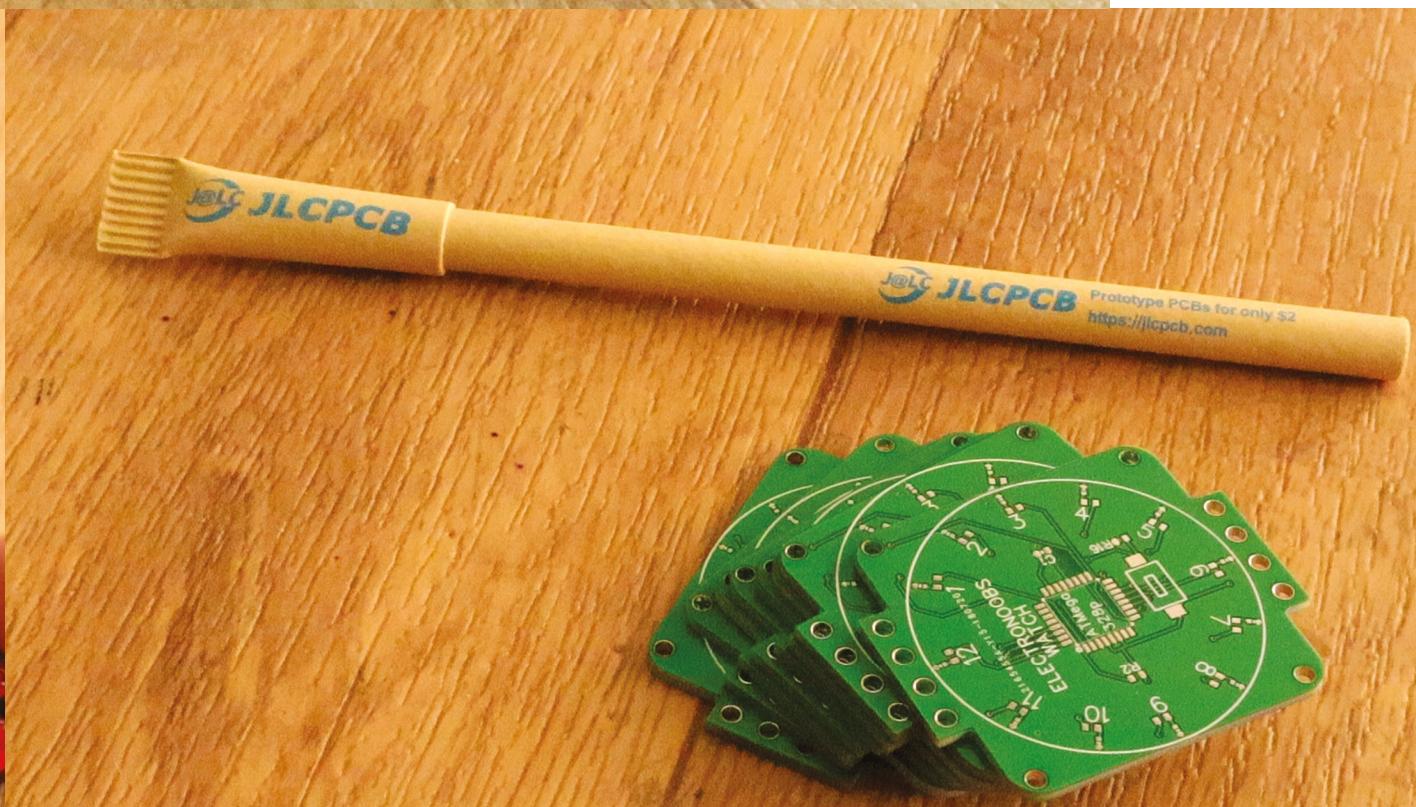
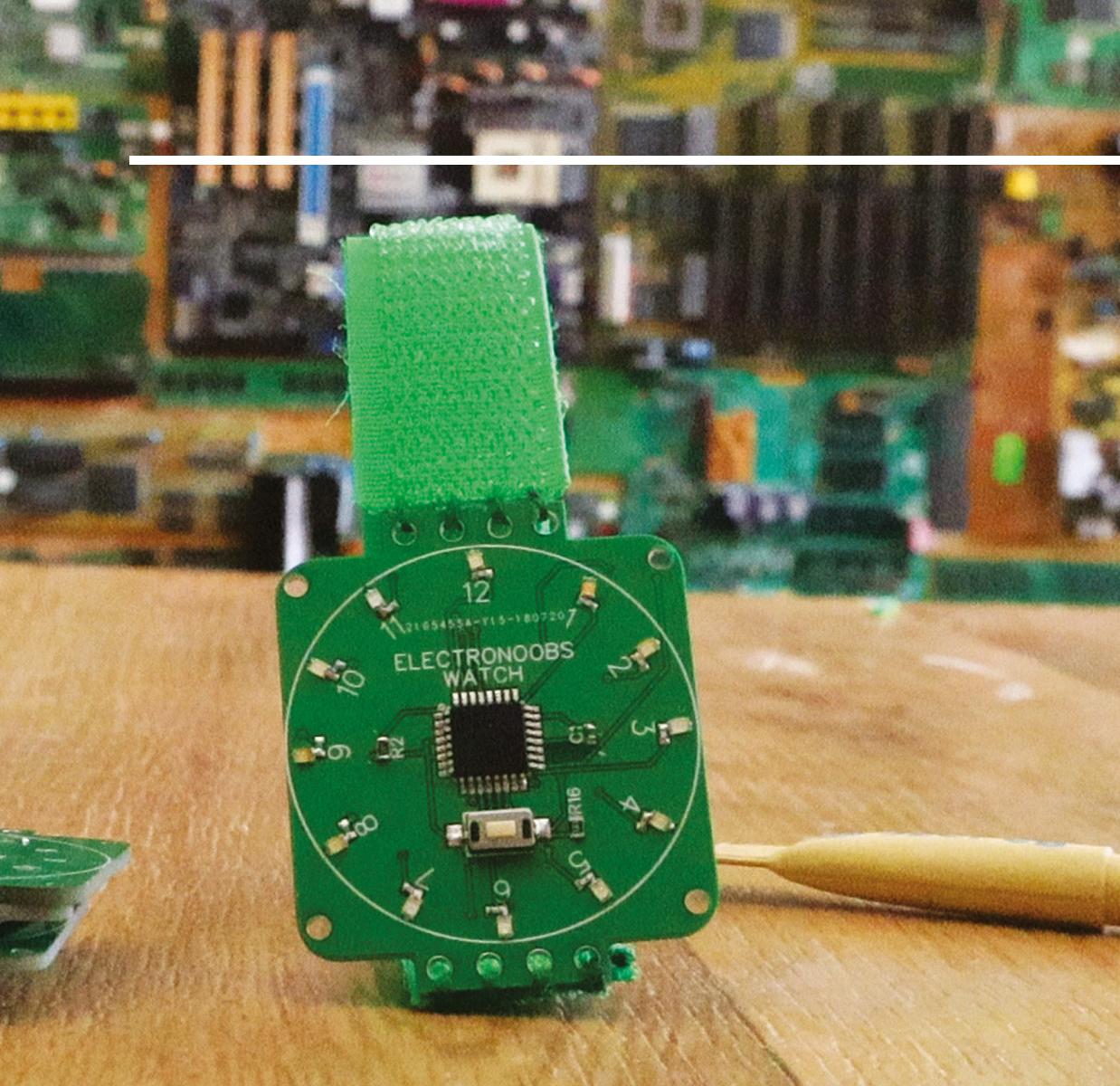
I think it looks quite geeky and it's a good project to make at home and learn at the same time. □



**Right** □

We've seen a few PCB designs used as clock-faces, but this must be the simplest







# Waterwheel pump

By Nick Watson

 backtotheland.co.nz

**M**y partner and I moved to a small farm from New Zealand's big smoke, Auckland, four years ago. Since then, we've come to understand the farmer's plight – doing more with less. One such venture was constructing a waterwheel and piston pump to replace the worn-out petrol-powered pump down by the river, which supplied water to our stock tanks. We needed to pump approximately 2000 litres per day, 20 metres high.

I first considered a hydraulic ram pump or a Wirtz wheel, but the calculations seemed dubious for our setup. So, I set out to craft a simple waterwheel-driven piston pump, with only an instinct for how such a thing might function. Surprisingly, the hare-brained prototype worked. The waterwheel is comprised of wood with metal fins. An iron wheel at the end of the axle drives a simple Scotch yoke mechanism, which pushes the piston. I didn't want to buy expensive check valves for the pump, so I crafted my own out of rubber bouncy balls and PVC couplings. Works like a charm! □



**Right** □

First rule of farming:  
if something's free  
(such as the energy in  
this stream), use it!



# Arc reactor

By Mari DeGrazia

@MariDeGrazia

**recently spoke at a conference where the theme included superheroes.** To that end, I made Iron

Man's Arc Reactor. It's enclosed in a 3D-printed case, with two WS2812 LED rings. It's driven by a Gemma M0, and can run off a small LiPo battery.

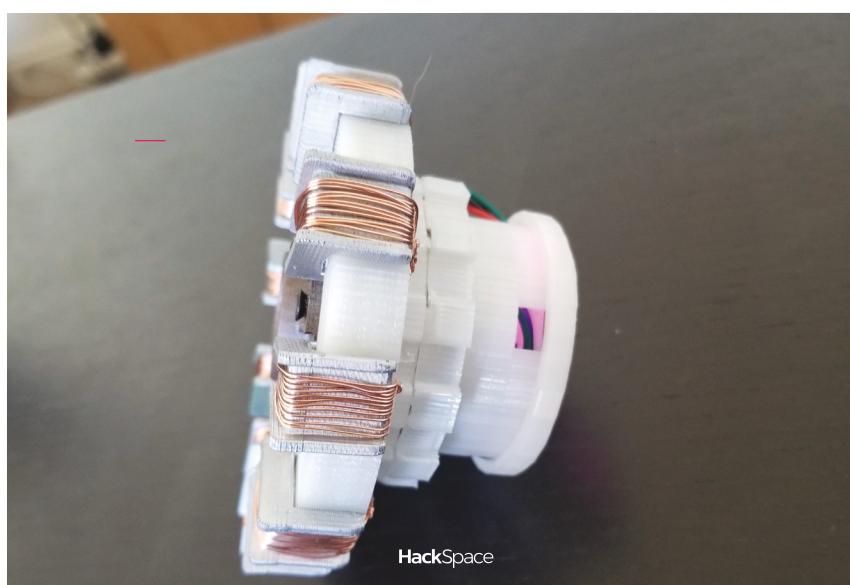
There is a button on the back that lets the user cycle through various LED patterns. The Gemma can also be powered by a USB device – which gives two ways to make it portable.

This project is an amalgamation/hack of various other projects. I modified an existing 3D-printed case from Thingiverse for the Arc Reactor, and designed the case for the Gemma and battery on the back.

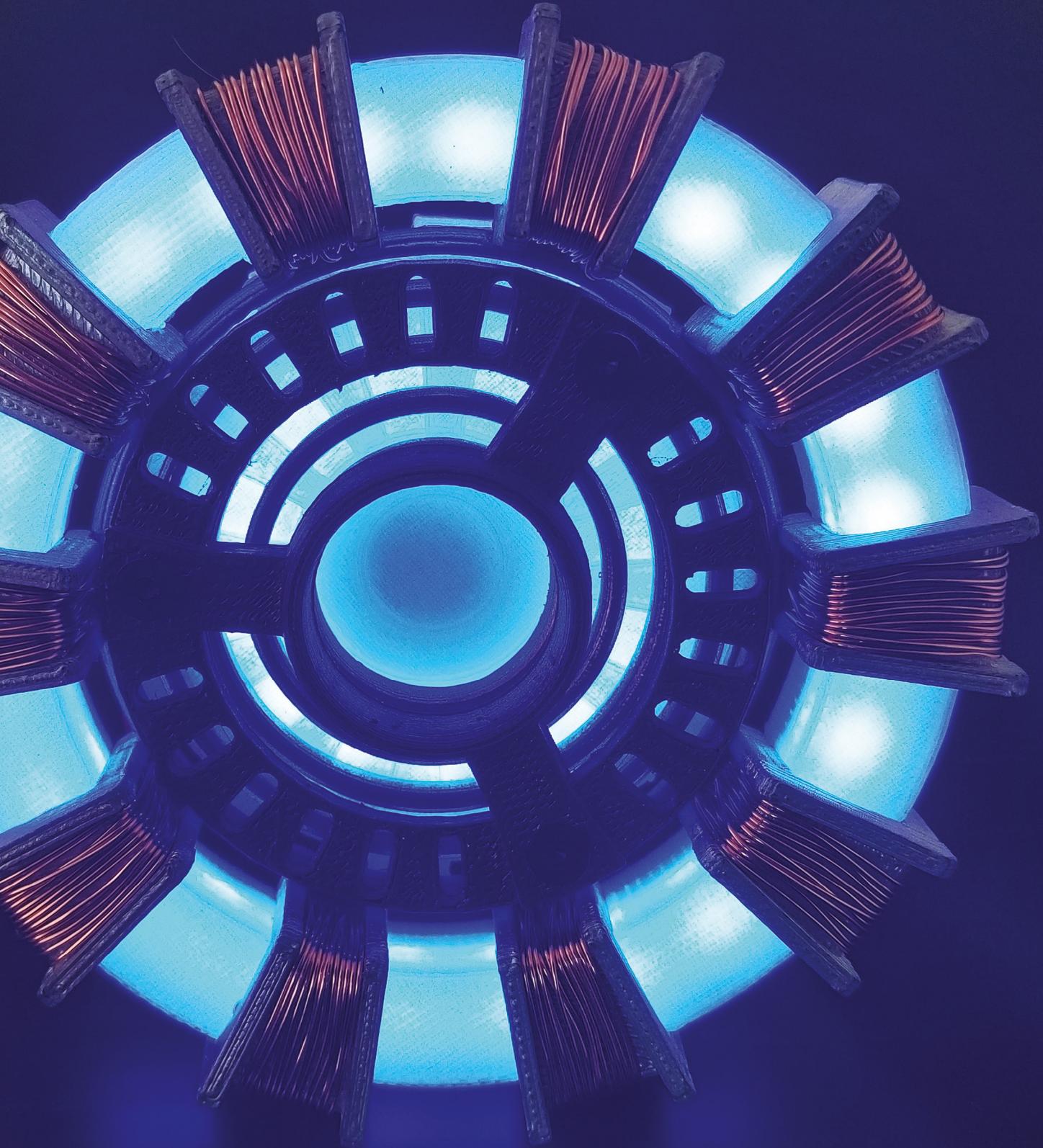
I work in cybersecurity, doing Digital Forensics and Incident Response, working large data breach cases. In a professional capacity, I've been technical editor on a couple of forensic books, authored some magazine articles, and I write a blog, as well as forensic tools and scripts. I am *big* on open-source and giving back to the community, which drives a lot of what I do.

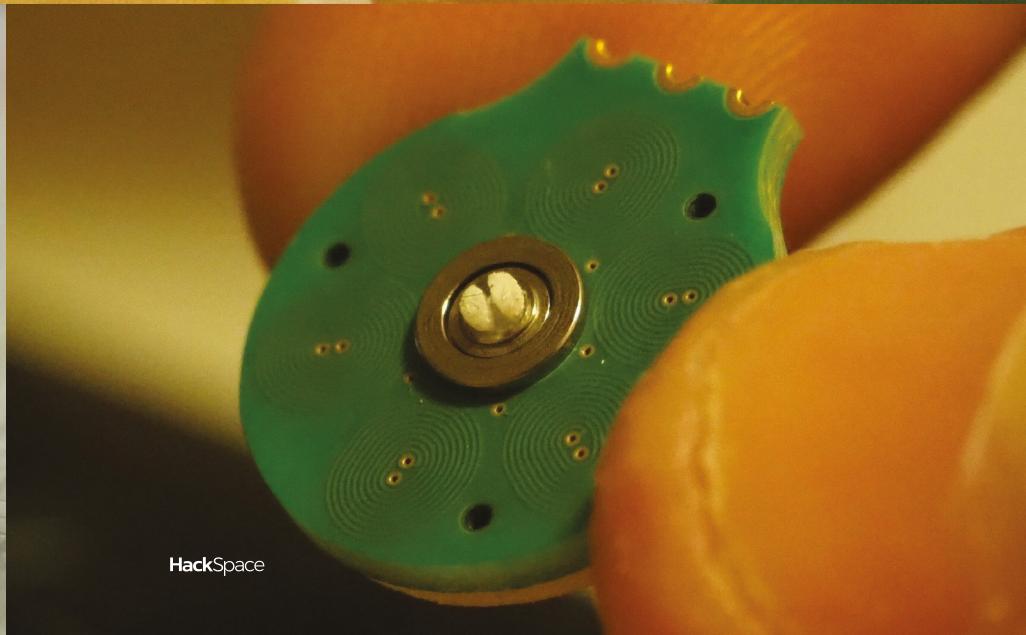
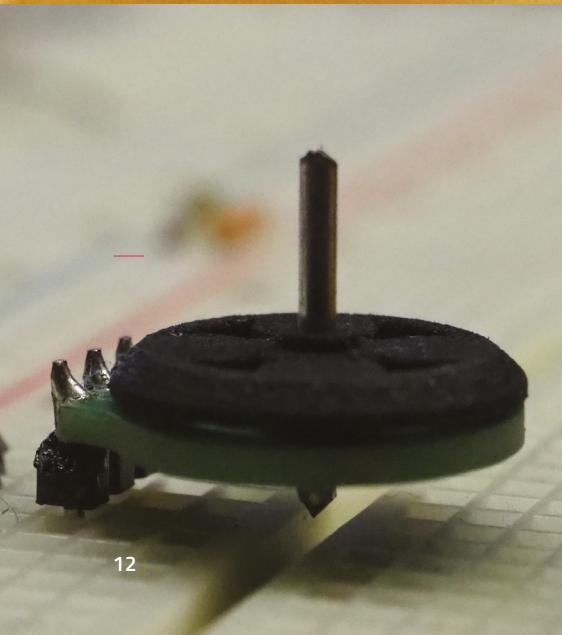
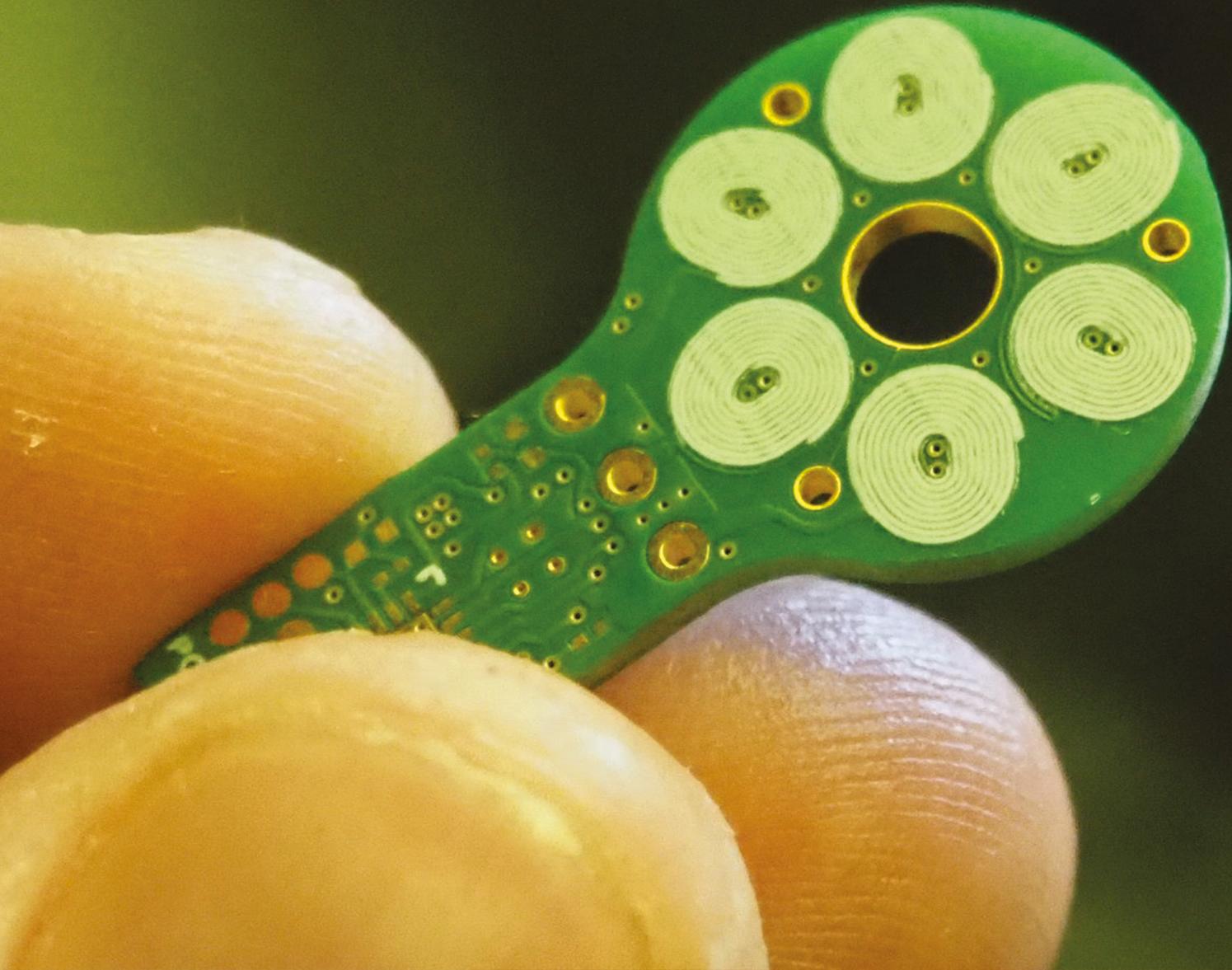
On a personal level, I spend my spare time working on maker projects, and I also organise and volunteer at a free 'smARTMAKER' lab for kids 12+ once a month. Although the lab is open to all, I am hoping to attract more girls into STEM by providing an environment that they will feel welcome in, and projects that will appeal to all. I recently did a week-long maker camp for kids, and had a blast. □

**Right** □  
Tony Stark built this  
in a cave. Imagine  
what you could do!



HackSpace





# PCB motor

By Carl Bugeja

 [youtube.com/carlbugaja](https://youtube.com/carlbugaja)

**T**his open-source PCB motor is a small, cheap, and easy-to-assemble micro brushless motor.

What's unique about this motor design is that the stator is printed on a four-layer PCB board. The six stator poles are spiral traces wound in a star configuration. Although these coils produce less torque compared to an iron core stator, the motor is still suitable for high-speed applications.

Creating a brushless motor using a PCB is cheaper to manufacture, and allows the designer to easily tailor the design to their specific project. This design is lighter than standard brushless motors, which opens up countless opportunities for smaller, more delicate projects. □



**Left** □

The stator is the stationary or static part of the motor, and holds electromagnets (coils) in place – the rotor's (movable part of the motor) magnets interact with the motor's coils, making the rotor spin around the stator

# LEGO game

By Eugene Oleynik

 [hsmag.cc/aFqBZJ](http://hsmag.cc/aFqBZJ)

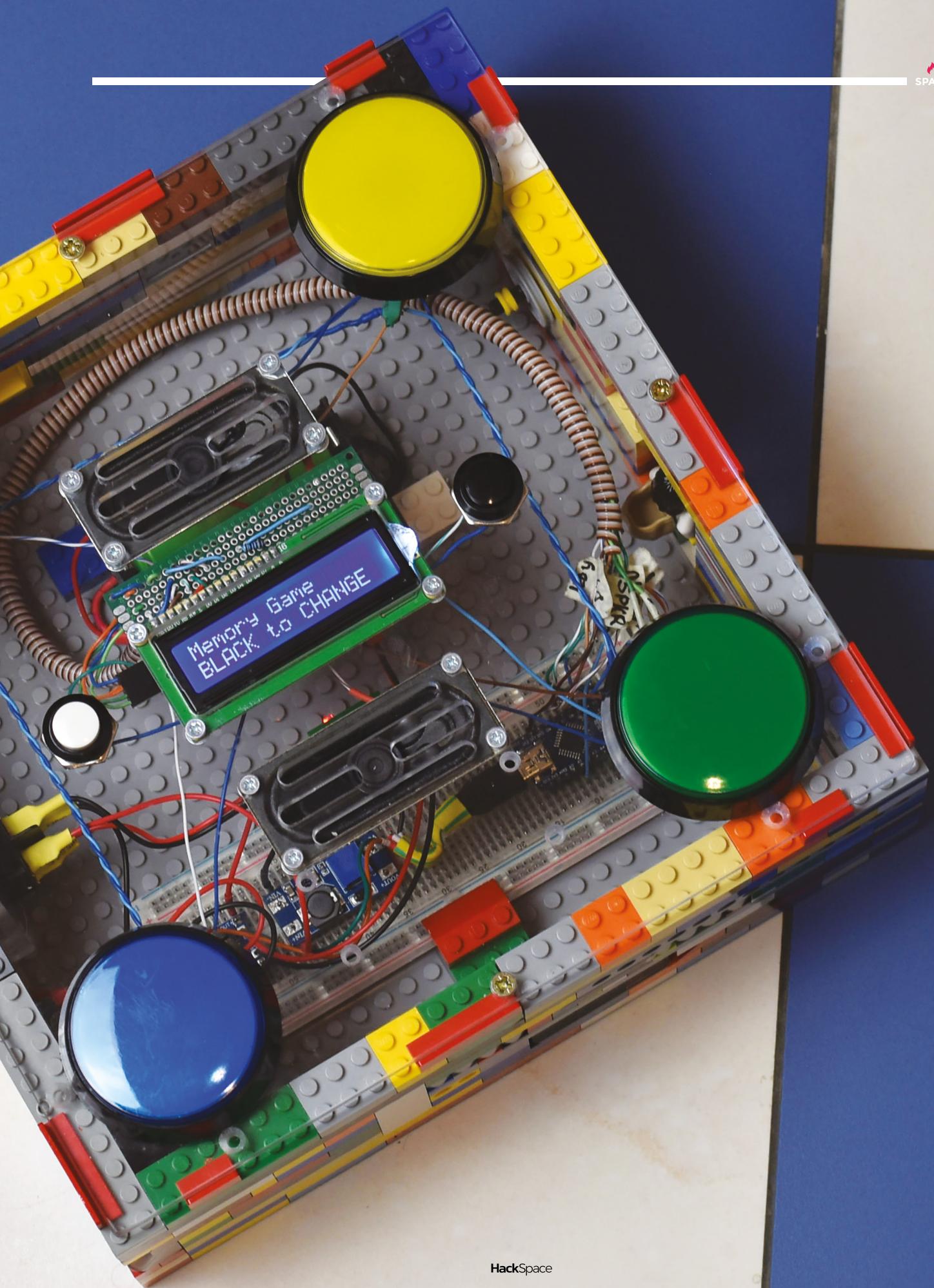
The game we built is a consequence of a dilemma we had in the family – kids play with LEGO bricks, and eventually all sets end up as a single pile of random bricks. That's how the enclosure for the game was made. When building this game, the main idea was to make it as simple and low-cost as possible, so that everyone could repeat it, even without programming skills. For example,

- We're using 1602 LCD display – this is the most widespread low-cost display for the Arduinos.
- The rechargeable battery cells for this project are free – they are recycled from a dead laptop battery.
- The recharging can be done using a standard mobile phone cable (micro USB).
- For electronics assembly, we used Arduino Nano, wires ripped out from unwanted twisted pair network cable, and a breadboard.
- The top faceplate is a simple CAD drawing that we cut in the CNC shop.
- Small speakers are from an old TV, and Mario in-game sounds are produced by an Arduino, without additional sound modules (!) – credit goes to Reyboz for this.

What came out is an arcade-style box that has five casual games: a Simon Says-like (memory) game, a reaction game (Whack-a-Mole-type), a contest game for two-four people (who presses the button first), a music game for toddlers, and finally a war game for two-four adults. □

**Right**  If you're going to have a button, have a big button





# Objet 3d'art

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**H**arvest time has come around again, and that gives ample opportunities for assembling still life compositions of the stuff you've grown in your allotment. Or bought from the shop, if you want to fake it.

Thingiverse user John Mulac has come up with this ingenious take on a traditional collapsible basket that folds flat when you don't need it. □

↗ [hsmag.cc/zTVjgJ](http://hsmag.cc/zTVjgJ)





If you remember reading issue 1 of HackSpace magazine (and if you don't remember, refresh your memory at [hsmag.cc/issue1](http://hsmag.cc/issue1)), your brain is probably still reeling at the thought of building a miniature trebuchet. In the same theme, here's another homemade siege engine.

This simple catapult, by Luke Tansell, relies on a twisting motion in the arm of the catapult to impart the energy to the projectile, so you have to use a material that will flex a little: Luke recommends using ABS/PC. □

↗ [hsmag.cc/IQLCxU](http://hsmag.cc/IQLCxU)

# Meet The Maker: Martin Mander

Breathing new life into old technology



**M**

**any makers who we speak to take pride in making something that will last long enough, and be of a high enough quality, that people will appreciate it far into the future.** Martin Mander takes

that idea one step further: he finds old technology that has been discarded and gives it a new lease of life.

He mostly uses the Raspberry Pi, with a smattering of micro:bit and Arduino, as and when the project calls for it. Most importantly, each new object is inspired in some way from the thing it's made out of. We met Martin at Raspberry Fields to find out how he does what he does, and came away with some wisdom that all upcyclers could learn from...

**I'm passionate about upcycling old technology with the Raspberry Pi. I've always been tinkering with old electronics**

I'm passionate about upcycling old technology with the Raspberry Pi. I've always been tinkering with old electronics but, before we discovered the Raspberry Pi, I used to do old tech conversions on old TVs, putting big flat panels in there, and chopping them down to make them a more sensible size.

The disadvantage of all of these pre-Pi projects was that you still needed a computer to hook them up to. So, you'd have it mounted on the wall, but you'd only be able to get it working if there was also a wire connecting it to a desktop computer, or a laptop, or something like that. When I published

the build for one of my TV projects, one of the commenters on the website said, "Why don't you put a Raspberry Pi in it? Then you can do the whole thing in one."

I said whoa, I'd never heard of this, but I'll give it a go. It's been a marriage made in heaven since then, doing old tech conversions and using a Raspberry Pi.

My first Raspberry Pi project was the VCR, which has a Raspberry Pi 1. It's got a USB hub in the front, a 14-inch HD panel in the rear, and it runs a distribution of Kodi, so it's a media centre. It was my first Pi project, but it did take about nine months to complete, so it wasn't the quickest of things. After that, I converted a Bang & Olufsen cassette player into an internet radio, which again was lots of fun, but took about six months. So, we moved on to smaller things.

The first thing that I've managed to do with the Raspberry Pi this year is this little game: the Rabbit Ears of Doom. You've got a Betamax remote control with a Raspberry Pi, you start on one side of the rabbit ears, and you've got to get it all the way round to the other side, and touch a metal contact to win the game. But while you're doing that, you wear a pair of glasses that have various LCD shutters in them. As you try to move around the rabbit ears, your vision is being interrupted, one eye at a time, just to make it extra hard.

Apart from the Raspberry Pi and new accessories, all of it was free. All of it was given to us at the end of car boot sales by somebody who just didn't want to take it home, given to us by relatives, or it was found and we bought it for about 50p... it shows just how accessible it can be to take old tech, stick a Pi in it, and create a really unique project. ➤

**Below** Items with large bodies often need internal structures adding to them – Martin uses LEGO



### WHY OLD TECH?

One of the main things is that tech from the 1960s, 1970s, the 1980s, it's all screwed together. It wasn't clipped together, it wasn't glued together, you don't need to buy a set of tools off eBay to pry it open. You just need a screwdriver and you can take it apart. And that makes it really accessible, really fun, you can take it apart really easily.

Another reason is: old tech big, new tech small. To do something fancy with electronics back in the 1970s, you needed a massive amount of circuit boards and components. But nowadays, we only need a little bit. So, when you take an old piece of tech and you rip its guts out, all of a sudden you've got loads of space to put a speaker in, some lights, some motors. It really frees up what you can do inside the case of a classic bit of tech.

### TIME TO MAKE

I know a lot of people at work who say: "Oh yeah, I want to get a Raspberry Pi, but I just can't decide what to do with it." What we do is approach it from the other end. Go down the car boot sale, find something that we really like – Julian (Martin's son), sitting there, usually does the negotiating so that we get the cute face discount, get a bit of money knocked off – £2

**Below** Lots of the kits that Martin makes find a use in his home. Groovy, baby!

instead of £3, that sort of thing – but we start with the object. We find something that we really like, so radio, TV, cassette player, hair-dryer, whatever it might be.

Once we've got something, we think : "Okay, we've got this thing that we really like the look of, what should we make it do? Shall we make it light up, or make a noise, or run around the room screaming

"We've got this thing and we're trying to work out how to do something with it. Once we've got that, we know what techniques to research"

every time it detects motion in the front garden?" And that's what decides the direction of the project. We've got this thing and we're trying to work out how to do something with it. Once we've got that, we know what techniques to research, and maybe what accessories we need to get. So, we learn new techniques every time.





**Above** The Pi VCR brings a Raspberry Pi and a flat screen into the body of an old video recorder



**Left** The Pi has enabled Martin to get into Python programming, to automate the moving parts of his builds

## BARGAINS TO BE HAD

Car boot sales are absolutely the best place to find old tech, because they want rid of stuff, and at the end of the car boot sale, they don't want to take it home again. Where we often score is towards the end of the car boot, or if it starts raining, people are just literally giving stuff away, 50p here, or £1 there.

Gumtree is also great, again, people just want rid of it. If you're going to go to their house and relieve them of something, especially if it's a bulky old TV or something, you won't need to pay them much money.

If you're looking for something on eBay, obviously with the current trend for vintage and retro, if you search for either of those terms, it's going to be overpriced. You're better off looking for spares and repairs, or broken. If you're going to take its guts out, or if you're going to paint it anyway, it doesn't really matter that it's broken. It's almost better that it's broken, because then you don't feel bad about taking it apart.

## TOP TIPS FOR UPCYCLERS

Think beforehand about what you want to achieve. Safety first, especially with old TVs. Be careful before you take all the parts out, a lot of it is mains electronics. Document any dismantling; I usually take a lot of photos or videos when we're taking something apart, because it might take a month to do the project, and by then you'll have completely forgotten what goes where.

Keep all the parts. We have a magnetic parts tray and that's just brilliant, because you can chuck a screw in and it sticks.

Where possible, use the original features. If you can use the original switches, knobs, or sliders, and

integrate them with the GPIO on the Pi, it really adds to the project.

Once you get the case open and pull all the electronics out, there are very often lots of plastic posts in there that need to come out, and the rotary tool is great for getting those out, great for cutting holes. Or, if you want to mount a little LCD screen in there, a rotary tool is your best friend for cutting apertures.

Hot glue gun: I realised recently that you can get black hot glue. It's my favourite thing in the world now. You can use it to fill gaps in black plastic, and it dries with a really good sheen.

Lastly, a multimeter – if you're using the original controls, you'll definitely want one off these, as that will help you decide how the original switch was wired, because that can be an education in itself, and then how you can use that to connect a GPIO to run functions on the Pi. □

**Below** This brave child is about to take on the Rabbit Ears of Doom



# Robots

Making computers move



**Lucy Rogers**

 @DrLucyRogers

Lucy wrote a forward to the book *Robot: Meet the Machines of the Future*. Aimed at the 9+ age group, it gives an introduction to the history of robotics, defines a robot, and explores how they work. It also mentions robots such as Nao, Pepper, PackBot, PARO and Latro.

**T**in foil, cardboard boxes, and a funny voice were all that seven-year-old me needed to become a robot. It was my attire of choice for fancy dress parties.

It wasn't until I was a teenager and reading Isaac Asimov's *Robots and Empire* series, that I really got to 'believe' in robots. One of the main characters was R. Daneel Olivaw ([hsmag.cc/SBZizD](http://hsmag.cc/SBZizD)), a humanoid robot that could easily pass as human. For me, every real life robot I meet, work with, or see, gets measured against that fictional benchmark.

Admittedly, robots nowadays are a lot closer to that ideal than they were when I was a teenager. But they are still currently falling short.

At the moment, we need to learn the language of the robot (or computer) in order to talk with it. Although Grace Hopper invented the concept of a compiler, which meant we no longer had to program computers in 1's and 0's, FLOW-MATIC, Fortran, and Python are not the languages spoken on the street.

Even computers programmed to understand our speech or 'natural language' still need us to behave – "Alexa, turn off the living room lights", may get the right response. "Alexa, turn the lights in the living room off", probably won't.

We no longer need to be a huge company or government agency to be able to build a robot. There are plenty

of kit robots that we can make and program, or we can make them ourselves. The Pi Wars competition, ([piwars.org/2019-competition](https://piwars.org/2019-competition) – take a look in issue 9 for more info), is a great example of what can be done. The event is based on a set of challenges – some autonomous, some using remote control, and there are various levels, so no matter your skill at programming, you can still compete in everything.

There are a lot of robots out in the wild – and many opportunities to interact with them. Pepper and Nao are humanoid and interact with humans

– I've had the chance to play with them both and they are fun! Sir Killalot and Matilda from *Robot Wars* are, admittedly, remote control, but they are at

**For me, every real life robot I meet, work with, or see, gets measured against that fictional benchmark**

many science fair-style events, and you can get to meet them too. Ones that I am glad exist, but don't really want to meet on a dark night, include; PackBot – which is used on dangerous missions such as bomb disposal and for chemical detection, and the spider-bot Latro, which was originally designed to clean up Sellafield nuclear storage site. I am yet to meet the cuddly seal, PARO – designed for use in hospitals and nursing homes as a form of pet therapy. I am now wondering whether I should make my own version... □

# SoCs: when to make versus when to buy

Focus on what makes your product unique



**Bunnie Huang**

@bunniestudios

Andrew ‘Bunnie’ Huang is a hacker by night, entrepreneur by day, and writer by procrastination. He’s a co-founder of Chibitronics, troublemaker-at-large for the MIT Media Lab, and a mentor for HAX in Shenzhen.

**M**

any internet-connected embedded products today run some flavour of Linux, and Linux requires a reasonably sophisticated System on Chip (SoC). The underlying hardware implementation typically boils down to the venerable CPU-RAM-ROM triad, a motif found under the hood of virtually every computer for decades. This triad of components is technically challenging to implement, yet ironically is one of the least differentiating features.

Product developers that prioritise BOM cost reductions will blindly throw extensive engineering resources at refining and cost-optimising the CPU-RAM-ROM

triad. It seems easy to justify throwing resources at a full-custom solution that can shave tens of dollars off a BOM, which would otherwise go to a System on Module (SoM) vendor like Raspberry Pi, Variscite ([www.variscite.com](http://www.variscite.com)), or SolidRun ([www.solid-run.com](http://www.solid-run.com)). This is sound logic if you’re a large corporation gearing up for production runs of hundreds of thousands of units.

However, even the most successful startup products typically run only a few thousand units before requiring a major design revision: bold new ideas make bold assumptions that rarely survive contact with end customers. Fresh

clarity on market requirements and user feedback often necessitates changes. In a fail-forward-fast environment, cost-optimising a CPU-RAM-ROM triad doesn’t make sense. It would be like assigning top software developers to first hand-optimise code loops, instead of experimenting with new features and user requirements.

When design requirements are bound to change within the span of a few thousand units, spending tens of dollars extra per unit to buy a modularised CPU-RAM-ROM triad from SoM vendors amortises nicely, compared to the costs required to roll one from scratch.

**Fresh clarity on market requirements and user feedback often necessitates modifying the SoC core**

Starting with a well-validated processing core also reduces the risk of schedule delays due to unforeseen complications, while freeing up

engineering resources to work on features that are truly unique to your product.

A real life example of this philosophy is Formlabs’ choice to use a SoM inside the Form 2 (read the full tear-down here: [hsmag.cc/MPWHAP](http://hsmag.cc/MPWHAP)). Despite having ample venture capital and engineering resources, they wisely focused their efforts on building a better printer, instead of a cheaper or better computer. The wisdom to see past the BOM, and to focus on the issues that make or break a product, is arguably one of the essential competencies that any startup needs if it hopes to eventually grow into a billion-dollar business. □

# Letters

## ATTENTION ALL MAKERS!

If you have something you'd like to get off your chest (or even throw a word of praise in our direction) let us know at [hsmag.cc/hello](http://hsmag.cc/hello)



### TANDOORI DREAMS

I got the magazine [issue 10] on Thursday, I bought some flower pots, and built the tandoor on Saturday morning, and I had my first home-cooked tandoori chicken that evening. What a brilliant project, keep them coming.

**James Spencer**

Leicester

**Ben says:** The tandoor oven that I built for issue 10 was quick and cheap, but the results were (if I may be allowed to blow my own trumpet), magnificent. If you're a human who likes to convert food into chemical energy, I totally recommend you try it.

### CAPS OFF

After years of using the little buggers, I never understood exactly what capacitance is. It was explained to me as like filling a bath with electrons, which sounds like gibberish. Well, I understand it now. Pass on my thanks to your writer.



**Mark**

Southampton

**Ben says:** When you look back at some of the rubbish that physics teachers come out with, it's a wonder that anyone sticks with the subject. Dave Astels's guide to electronics from the ground up continues on page 78 with inductance.

### WHAT TOOLS?

I appreciate the power tools guides – I've bought a bench grinder, but the ripsaw looks like overkill for my needs – but how about a little more on hand tools? There must be about a million types

of saw for one and, even if you're not in the market, it's nice to look at some shiny hardware.

**David**

Lewes

**Ben says:** It sounds like you're talking specifically about woodworking tools. We're very much of the bash-it-together school rather than the fine dovetails, so unless we find a woodworking expert (and we are looking!), we'll stick with quick and easy methods, such as the pocket screw setup on page 112.





When backing a crowdfunding campaign, you are not purchasing a finished product, but supporting a project working on something new. There is a very real chance that the product will never ship and you'll lose your money. It's a great way to support projects you like and get some cheap hardware in the process, but if you use it purely as a chance to snag cheap stuff, you may find that you get burned.

# CROWDFUNDING NOW

## Retro-uC

Why pick a favourite processor when you can have three?

From \$42 + [hsmag.cc/hhSOQq](http://hsmag.cc/hhSOQq) | Delivery: March 2019

**W**hat's the best retro processor? We've featured the Z80 in this magazine before, but there are also fans of the 6502 and the M68K. If you were going to try recreating one, which would you go for?

Well, the good people at Chips4Makers decided to go for all three in a single tri-core CPU that includes 4kB of on-chip RAM, 72 GPIOs, and a JTAG for programming. You can use some of the IO pins to select the core that's active when you reset the chip.

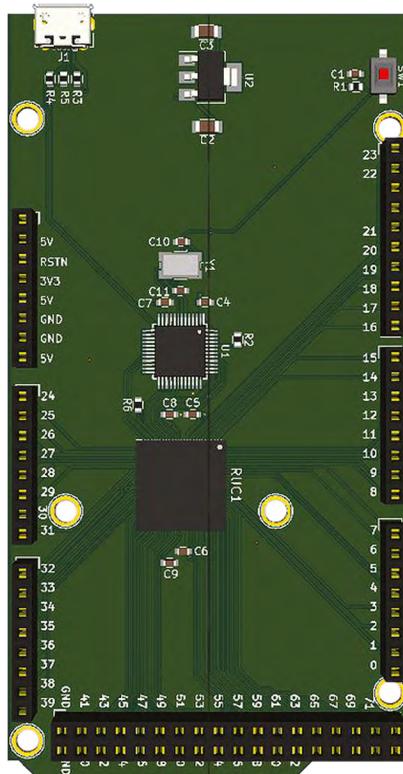
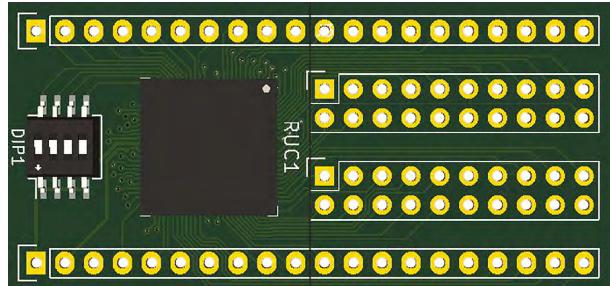
There are a few options for people supporting the campaign. If you're looking to build your own boards, you can get individual chips for \$42, a small breadboard-compatible break out for \$59, and a couple of other options that include the chip on protoboard.

If you'd rather start with a more familiar form factor, there's an Arduino Mega-compatible module for \$89

If you'd rather start with a more familiar form factor, there's an Arduino Mega-compatible module for \$89.

The chips will be manufactured using the 350 nm process that first came out in 1995. To put this into context, the current state-of-the art is 7 nm. However, the great thing about retro processors is that there's no need to chase the latest technology. The state-of-the-art in the mid 1970's (when these cores were first released), was around 5 µm. Which means that now, it's far more affordable to do a low-volume tape-out.

Chips4Makers are working in the open, and all the source code for the chips is available at [hsmag.cc/FCqmYP](http://hsmag.cc/FCqmYP). □



**Above** This has a switch that lets you choose the CPU architecture to boot

**Left** Ever wanted to build a computer that's compatible with both Apple II and Arduino? This is your board

# Space of the month: Fab Lab Sandwell College



Fab Lab  
Sandwell College

[sandwell.ac.uk](http://sandwell.ac.uk)

**F**ab Lab Sandwell College is a thriving space, enabling many different types of people to make many different things. We aim to make making easier. We are located in Sandwell College's sixth form centre and do many things for the students, but we have all sorts of people coming in using the space, which is great. We aim for low floor, high ceiling activities – so there's no barrier to entry, but you can keep going as far as you like. In one day we might do a workshop for young children, which may be mainly colouring or gluing and sticking, as well as a PhD-level project, like helping someone develop a new way of plating aluminium.

We have the full Fab Lab list of equipment, which includes laser cutters, 3D printers, CNC machines, vinyl cutter, etc. The claim is that you should be able to make almost anything with the machines we have! But what really makes the Fab Lab is the people who come in and use the machines: they are endlessly creative, and just spending time in the place can inspire you to make more things than you have time left in the world.

## SCRAPHEAPER IN CHIEF

The Fab Lab is run by Anne Scrimshaw, most famous for being judge and team captain opposite Dick Strawbridge on early episodes of TV makerfest *Scrapheap Challenge*. She also built and raced hovercraft at a national and international level for 20 years. All of which means crazy build suggestions are a part of normal life. Having always loved making *nearly* anything, now she's running the Lab, Anne can make even more. With a degree in automotive engineering, as well as going to art college, she has worked as both an engineer and an art teacher.

The Giant Selfie Christmas card is a good demonstration of some of her skills. The original design was drawn in Inkscape, then transferred to the ShopBot CNC machine to cut the MDF to shape. Then the design was hand-painted with acrylic paint, and a Bare Conductive capacitive touch board was attached with conductive thread and paint to laser-cut decorations. When the decorations are touched, the card will play Christmas carols.

Some of the other people who come to the Fab Lab include Matt Lloyd from Infamous Community Arts. Matt uses the Fab Lab when he has some large wood carving to be done. The ShopBot CNC machine

“  
We aim for low floor, high ceiling activities – so there's no barrier to entry, but you can keep going as far as you like

is great at cutting circles, gears, or carving lettering. It will also carve full 3D from an STL file, so having done mini-me 3D prints, we keep intending to machine a full-sized maxi-me! Maybe we aren't quite so narcissistic though, as we haven't found the time yet.

## FAB-RIC

Viv is a regular user. She is a textile artist and first came two years ago, and started laser-cutting a few things for her craft stall – some signs and cardboard iPads to demonstrate the iPad covers, plus fabric butterflies for her hats and bags. As time has gone on, she has become more adventurous, making 3D stands for display and all of her threads, as well as a set of small drawers downloaded from Thingiverse in the hope she might become organised, and she's used the large CNC machine to make a hat block. She has also collaborated with one of the students, combining 3D printing with fabric to make a flexible 3D print. It is fabulous to see people like Viv who →



Above ↗  
Things of beauty jostle with practical makes at Sandwell College's Fab Lab



**Above** This person's face is covered with a helmet, but we imagine they're grinning a grin of purest hovercraft joy

not only make amazing things but also end up changing what they think they are capable of, and even start making really quite cutting-edge things.

As we say, that is what makes the Fab Lab: the people. You see them sparking off each other, and it is quite contagious. The biggest problem is not having the time to make everything you would like to. Technology is changing and a tsunami of innovation is on its way. The question you have to ask yourself is: are you going to be swept away by it, or are you going to ride the wave?

Fab Lab Sandwell is a space located in the middle of West Bromwich, Birmingham. We are in the building formally known at the Public, which is now part of Sandwell College's sixth form centre. Although the Fab Lab is part of the college, and we do much for the students, we are also open to members of the public, and businesses.

Monday and Wednesday afternoons, 2pm–5pm, we have drop-in sessions, when it's free to come in and use the machines, but we ask people to pay for any materials they use. Individuals, businesses, and entrepreneurs can exclusively hire any of the machines at other times, and we currently have funding to offer the first twelve hours free – please apply now whilst the offer still stands! ☐

### CONTACT US

We'd love you to get in touch to showcase your makerspace and the things you're making. Drop us a line on Twitter @HackSpaceMag or email us at [hackspace@raspberrypi.org](mailto:hackspace@raspberrypi.org) with an outline of what makes your hackspace special and we'll take it from there.





**Below** ♦  
Just some of the projects that makers at Sandwell College have come up with



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ecia  
MEMBER

# LENS

HACK | MAKE | BUILD | CREATE

Uncover the technology that's powering the future

PG  
**48**

## HACKY RACERS



Introducing the ultimate in DIY electric-powered motorsport, right here in the UK

PG  
**52**

## PRECIOUS PLASTICS

How one homemade recycling system is changing how we deal with waste plastic

PG  
**58**

## INTERVIEW INSIDE AL'S HACK SHACK



We speak to one of the rising stars of YouTube and discover that we really need an angle grinder

PG  
**32**

## BEST MAKER HARDWARE

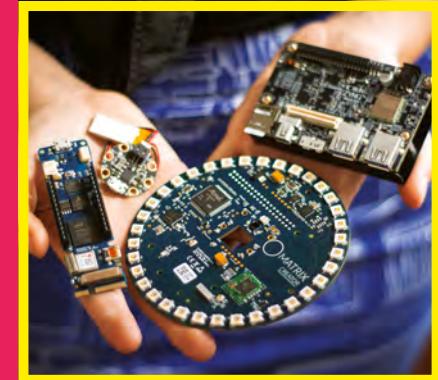
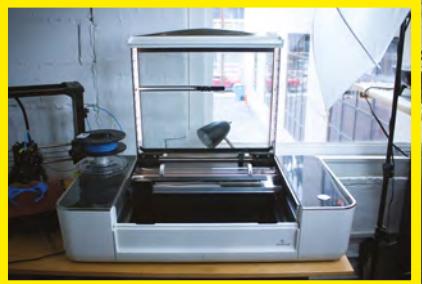
The lead hardware nerd of Hackster.io picks her top hacker tech for 2019

PG  
**66**

## IMPROVISER'S TOOLBOX CLOTHES PEG

It turns out that you can do rather a lot with two levers, a pivot, and a spring

# BEST MAKER HARDWARE



Alex Glow's guide to the year's best hackable technology





### **t's the golden age of making.**

It's never been easier to pick up programmable hardware or fabrication machines. However, this embarrassment of choices brings with it a problem (though it's a good problem to have). Out of all the available hardware, what are the best bits for your next project?

It's easy to keep using the same bits, just because they're familiar. Picking up the same microcontroller you first learned to use five years ago might feel like putting on a your old jumper at the first sign of a winter chill – safe, secure, and comforting. However, you're missing out on five years of improvements in processing power, connectivity, and electrical consumption.

If there's one maker technology that's really come of age in 2018, it's field-programmable gate arrays (FPGAs). This once arcane technology allows you to program the connections between logic units in chips, and this can mean the ability to process data at a rate that previously just wasn't possible on small, low-power boards.

The latest fabricators are easier to use and more accurate than ever before, and there's a great range of kits and assorted gadgets to make our lives easier.

All this can get a little overwhelming, so we've enlisted the help of a guide to help us navigate the avalanche of new technology.

Alex Glow is Hackster.io's lead Hardware Nerd, and every week she puts the latest gadgets, controllers, kits, and circuit boards through their paces. She's here to share what she's learned about the newest technology for makers, and to pick out the best bits.

Having the latest, shiniest bit of kit doesn't automatically turn you into a better maker, but it can make your builds a bit more straightforward. They can also open up new areas of making that may not be possible with older hardware. Now, sit back, relax, and have a look at the best new hardware for makers. Take it away Alex... →



**Alex Glow**

Twitter: @glowasci



Alex is the Hardware Nerd at Hackster. She tests out the latest technology and vlogs about it at [hsmag.cc/agXYIA](http://hsmag.cc/agXYIA)

## **TECHNOLOGY INSIDE:**

- > The best new microcontrollers [page 34](#)
- > Ultimate fabrication machines [page 36](#)
- > Easy-to-use FPGAs [page 38](#)
- > The best of the rest [page 40](#)
- > Hackable AI [page 42](#)
- > Gemma in depth [page 44](#)



# MICROCONTROLLERS

The brains at the heart of your projects



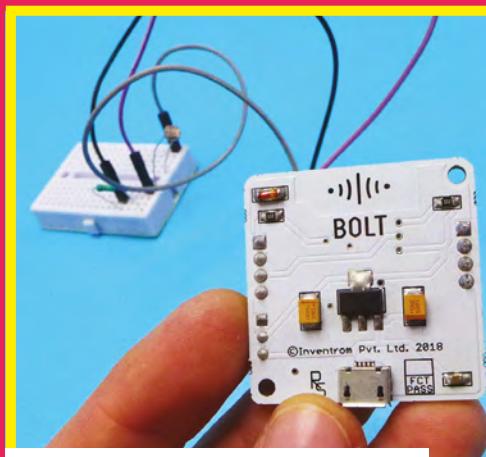
**M**icrocontrollers are the programmable brains of the electronic maker movement. They bring life to your projects, smarts to your mailbox, autonomy to your coffee machine. From the famous Arduino series (which has inspired a thousand adaptations), to incredibly niche custom boards, you can find a perfect microcontroller for virtually any application.

This tech is simpler than a single-board computer; it's typically used for basic processes that process input from one or more sensors and map it to responses, using a single 'thread' of logic. For that reason, microcontrollers may be used to offload routine processes from computers like the Raspberry Pi. (Some boards, like the UDOO series, incorporate both in a single package.)

As the microcontroller hobbyist scene matures, it's becoming popular among professional software developers who want to apply their skills to the physical world. We're seeing a rise in JavaScript (see Johnny-Five) and Python (see MicroPython and Adafruit's spinoff, CircuitPython). It's becoming easier to build your dream robot, home automation system, and more.

Meanwhile, block programming languages like Scratch and Blockly are making microcontrollers accessible even to toddlers. Every week, Kickstarter boasts new campaigns for child-friendly programmable robots. What a time to be alive!

I'm also a huge fan of the Gemma wearable controller, which I take a closer look at on page 44.



**B**olt IoT makes WiFi projects incredibly easy, and they've designed a beautiful kit. It runs on the popular, inexpensive ESP8266 platform, providing easy access to programmable pins and a handsome browser-based data tracking interface.

This one really stands out because of its user-friendly nature. It's obvious that the team have done their homework: the tutorials emphasise areas where newbies are likely to trip up, and the online interface is helpful without being condescending to experienced users. The first WiFi connection is made using a mobile app, which currently doesn't seem to do anything else, but I'm hoping for more functionality in the future.

Like all the best tools, Bolt has longevity because it can benefit domain experts as well. If you know how to run your own code on a virtual private server, you can use Bolt's APIs to poll sensors faster than the default five minutes. (A more 'resourceful' solution is to re-deploy your code through the browser in order to pull new data points.)

## BOLT IOT

Getting the internet into all the things

As an added bonus, it comes as part of a small kit including sensors, LEDs, and resistors. It takes about 15 minutes to deploy your first project. The Bolt team have published quite a few tutorials to introduce the platform; these cover the most popular IoT projects, including temperature/humidity monitoring, a smart pet feeder, and a voice-controlled light.

The basic kit will set you back \$23, and there are several other options, including multi-packs. □

## ALSO CONSIDER

When you need more power

We're only looking at microcontrollers here, but if you need more features or processing power, then single-board computers give you everything you have on a desktop in a tiny form factor. Boards such as The Raspberry Pi 3B+ pack plenty of processing power, and a fully fledged Linux system, into a great maker-friendly package.



## CYTRON - MAKER UNO

Everything you need to get started programming microcontrollers

**T**

**he Maker Uno is a \$6 Arduino Uno-alike produced by Malaysian company, Cytron.** It's designed specifically for teachers and young students of electronics: many of the pins have built-in indicator LEDs, and it also sports a piezo buzzer (a simple speaker), and a programmable button. Not only is the board itself super affordable, but you don't need any extra components or wires to get started! These days, most Arduino-style boards come with a built-in LED, but this one has twelve – one for each digital pin.

In keeping with the expected student audience, the board also has a place for each kid to write their name, which

should help stave off classroom brawls. Plus, the mute switch will help preserve teachers' sanity.

Designer Ober Choo has replaced the original Uno's USB B port with a micro USB port for power and programming, so people like me don't have to cannibalise our 3D printer cables. The board resolves many of the little roadblocks that arise during prototyping, enabling makers of all levels to keep momentum instead of being sidetracked by a thousand tiny tasks.

This board comes with a demo sketch that shows off some of its abilities, for a quick 'wow!' out-of-box experience. It's a solid pick for introducing children to microcontrollers. □

## TOMU

For when space is an issue

**T**

**omu is an unusual little board that fits almost entirely inside your USB port!** It has two LEDs (red and green) and a pair of capacitive touch sensors, which can be used for two-factor authentication, among other applications. It's a perfect platform for low-profile workflow augmentations, and reminds me a little of the BlinkM.

Tomu has achieved notoriety for its ability to transmit secret messages; you can encode text in an invisibly blinking LED, then decode them with the OpticSpy device (made by Joe Grand).

This board isn't yet Arduino-compatible, although some are working to fix that; in the meantime, you'll have to program it using the command line, but it's quite approachable. Or help improve it yourself, as the module and code are completely open-source!

There's even a (tiny) 3D-printable enclosure for it. You can get a Tomu for \$30, or two for just \$35. □



## PARTICLE ARGON

Keeping everything talking

**P**

**article's new Mesh boards deserve a mention, although they aren't yet released.**

Mesh networking allows every board (or node) in a network to relay messages to the others.

So, the physical size of your network is chiefly limited by the number of total devices the network can support. With just one WiFi or cellular node, you can connect the entire network to the cloud.

These boards use Adafruit's Feather form factor, which means they will be compatible with most Wings (like shields for Arduino boards), expanding the capabilities of your network.



They're useful for multi-sensor arrays and other outdoor or distributed applications.

The three options – Argon, Xenon, and Boron – are all capable of mesh networking and BLE, and two of them do WiFi or cellular as well; this is reflected in the prices, though all are affordable. For a good 'starter kit', I'd pick up the Argon (\$15) and a couple of Xenons (\$9) to build a baby mesh that can connect to the internet. □

# COMPUTER-CONTROLLED MAKING

Turn your digital designs into real-world objects

**F**abrication tools come in many varieties – broadly, you can think of additive (like 3D printing) and subtractive manufacturing (like laser-cutting or routing). All of

these methods are becoming more accessible, with broader price ranges and options that are suitable for small shops. There's even a new line of vacuum formers, directed at artists! (Injection moulding still needs to step up with some affordable options.)

Since most people don't collect 3D printers, and neither do I, I haven't included any in this section – but there are plenty to be excited about! Check out Kickstarter any week and you'll find a few cool new printers. Most makers are familiar with the MakerBot and/or Ultimaker lines, which easily run into the thousands of dollars, but now more low-cost options are emerging. Many of these are new resin-type printers with high resolution and small footprints. Just watch out for material costs, because they may run on the printer-ink profit model.

## BANTAM DESKTOP PCB MILL

**B**antam's desktop PCB mill short-cuts the process of prototyping your new PCB designs. If you need tight turnaround time, you have a few choices: etch away copper with corrosive chemicals, draw or paint your circuit with conductive ink, pay exorbitant fees for rush service, or mill your own.

Bantam's offering fits neatly on a desk and has an approachable getting-started process, which is friendly to first-timers. It takes a bit of practice to learn how the end mills (like drill bits) wear down during

Get your circuit boards when you need them

jobs, as well as how to switch them out, and how that may affect your design.

It costs \$3199 for the Basic model and \$3999 for the Advanced, which comes with an extra set of fixtures and tools for securing your material to the bed. In an interview with CEO Danielle Applestone, she told me that the most expensive part of the machine is the case – which includes routed channels for the wires, as well as magnets to hold the removable windows in place. However, it also uses a custom-designed motor that is designed for excellent precision at high speeds.

The mill includes a port for attaching a vacuum, so that you can pull out all the material debris: unlike a laser cutter, this machine produces a lot of dust that you don't want on your skin, especially if you're working with metal and/or fibreglass (as is the case with most PCBs).

You might be familiar with this company in its previous incarnation as the Othermill from Other Machine Co. They rebranded after being acquired by Bre Pettis, co-founder of MakerBot, in 2017.

If you're planning to get creative, I highly recommend Bantam's Instagram for beautiful inspiration beyond basic PCBs. □



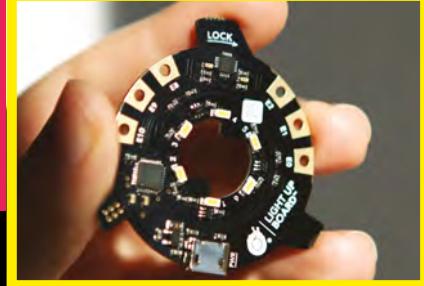


## GLOWFORGE

Cutting is easier when you add lasers

**T**he Glowforge isn't new, as of 2018, but it is still pretty fresh and prices are coming down, so it gets a mention. Glowforge set out to build a household laser cutter for consumers, and it shows: like Tinkercad for 3D modelling, it has an easy startup and people can create some beautiful objects. However, experts will soon bump their heads against a low ceiling of precision and control. The camera under the lid helps you place your design, which is great for visual alignment, but not always accurate. Plus, the interface prods you to use 'Proofgrade' materials – good for the novice who doesn't know which materials will release toxic fumes, or what settings to use, but a bit of a pain to work around.

Glowforge machines come in three flavours: the Plus version is 20% faster than the Basic, while the Pro allows you to feed material all the way through (and cut infinitely long things), with improved cooling for all-day jobs. Unless you really are a professional laser shop, it is probably not worth the upgrade – the Basic is speedy enough, and the power level is the same. Either gets you access to the Glowforge owner forum; I've seen many gorgeous and impressive projects in the digest. Prices here range from \$2495 to \$5995. □



## BARE CONDUCTIVE LIGHT UP BOARD

Keep your workshop perfectly lit

## SHAPER ORIGIN

Cutting large designs in small spaces

**I**got to try the Shaper Origin at Maker Faire last year, and it's a solid machine for routing out designs. The hand-held smart router doesn't require a huge dedicated space, like your typical ShopBot, and can be used on arbitrarily large and weirdly shaped materials. Score!

Its smart guide system is excellent and intuitive: first, you apply a patterned tape to your surface, which the Shaper uses for absolute positioning. Then, you trace out your pattern with the Shaper, as directed by the screen on top. Underneath, the end mill is adjusted within a few square inches, to ensure that the pattern is followed exactly. Shaper has made routing much more accessible – great for large robot parts, workshop signs, and more.

Pre-orders are sold out, but you can sign up at [shapertools.com](http://shapertools.com) to be notified when Origin hits the market. □

**B**are Conductive's Light Up Board is the soul of their Electric Paint Lamp Kit. The company's conductive paint kits are masterfully designed, and since this one comes with three lamp templates, the whole family (or office) can get their hands dirty. The board itself snaps into place in the folded paper lamps, which respond to touch and proximity. It's not a fabrication option by itself, but pair it up with any of the others here and you've got a lamp-creation workshop! The kit offers a wonderful balance of guided activity and creative freedom for \$45; you can also buy the board on its own for \$31.20 (excluding VAT). □



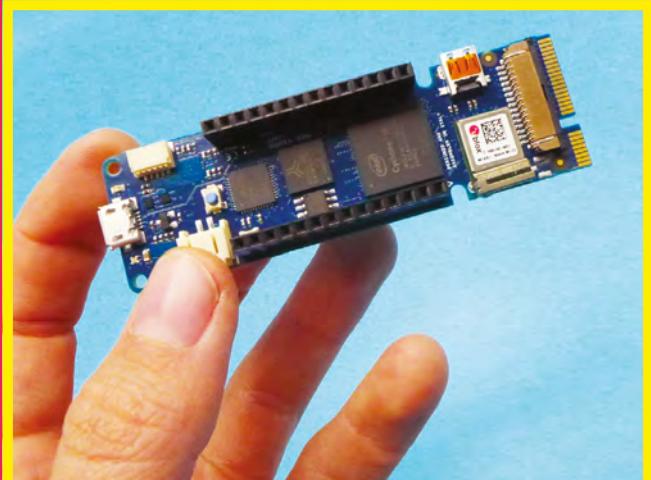
# FIELD-PROGRAMMABLE GATE ARRAYS

Custom silicon without the custom silicon

**F**PGAs! They're so hot right now! But what are they, and why should you care?

A field-programmable gate array is a group of logic gates that can be configured after manufacturing, so you can change the function of each pin at will (digital, analogue, PWM, RX/TX, and so on). Once you've configured your pins and connected them with chains of logic, data can flow through the circuit without ever touching your CPU – freeing up precious cycles. Thanks to parallel execution, you can process signals at high speed, delegate robotics responses, prototype your own chips, and massage audiovisual media without breaking a sweat. (Important side note: if your boards are sweating, that is bad.)

Do you have a high-powered project that's been waiting for the technology to catch up? These might be the answer. Read on for a few of my faves.



## MKR VIDOR 4000 – ARDUINO

**T**

The big new name here is the MKR Vidor 4000 – Arduino's first foray into FPGA territory. They're planning to release it with a ton of useful examples, which is one of the reasons Arduino continues to flourish: solid documentation and a large, sharing-oriented community.

So far, the Vidor is being marketed for high-speed audio and video processing. Yep, you read that right – video processing on an Arduino! Plug in a compatible camera on the built-in port and you can run an example that detects and opens QR codes. Nifty!

I had a bit of trouble uploading to this board from my computer, as my Arduino IDE didn't want to detect it (even after updating my Boards Manager). I took

the opportunity to try out Arduino's online programming interface, which found the Vidor with ease, and I hooked up an external monitor to its micro HDMI jack. Within seconds, the Arduino logo appeared on the monitor. Magic!

Next up, the company plans to

Bringing FPGAs to the masses



release a visual block language-based graphical interface for setting up your Vidor – making this even easier as a first step for the FPGA-curious. In the meantime, it's compatible with more traditional software tools.

As well as adding the Intel Cyclone 10 FPGA chip, Arduino has upgraded the usual ATMEGA128 or 328 to a SAMD21 microcontroller – the same one used in Adafruit's Gemma and Trinket M0 boards. This speedy chip adds some extra oomph, and the company plans to release example sketches that upload configurations to both chips in a single click.

The Vidor comes with WiFi and BLE compatibility, and I'm pleased to note that there's also a Microchip module for hardware-based security and cryptographic key storage. Get your hands on it for \$60. □



## ULTRA96

Bring on the power

**U**

Itra96 is a collaboration between Xilinx, Avnet, and Linaro, and it's a powerhouse for the software-savvy developer.

The showcase demo is a convolutional neural net that performs image classification 6000 times faster than a standard processor, thanks to parallel processing. After splitting each image into multiple tiles, the Ultra96 can analyse many tiles at once, avoiding the usual bottleneck.

The workhorse here is a Zynq UltraScale+ MPSoC.

The '96' in the name comes from 96Boards, an organisation that's working to make ARM chips more accessible to developers. With this hardware standard, one can easily drop in a new chip and wire it up to expected inputs and outputs. This makes the Ultra96 immediately compatible with existing 'mezzanine' boards for audio, security applications, and more.

The standard also provides a 40-pin low-speed expansion header and a 60-pin high-speed header. Ultra96 is about the same size as a Raspberry Pi and equipped with WiFi and Bluetooth.

Interestingly, the \$250 board comes with a one-year licence for the Xilinx SDSoC software – an Eclipse plug-in which enables you to program FPGAs in C, and usually costs about a thousand dollars. Therefore, it's actually cost-effective to buy a new Ultra96 every year and get the licence for free! □

**T**he TinyFPGA BX doesn't lie – it's a small board that packs a punch. Tiny price, too, at \$38!

Created by Luke Valenty, this mini-beast is powered by the Lattice ICE40LP8K chip, designed to save power. A great board to attach to a battery and tuck into tight spaces.

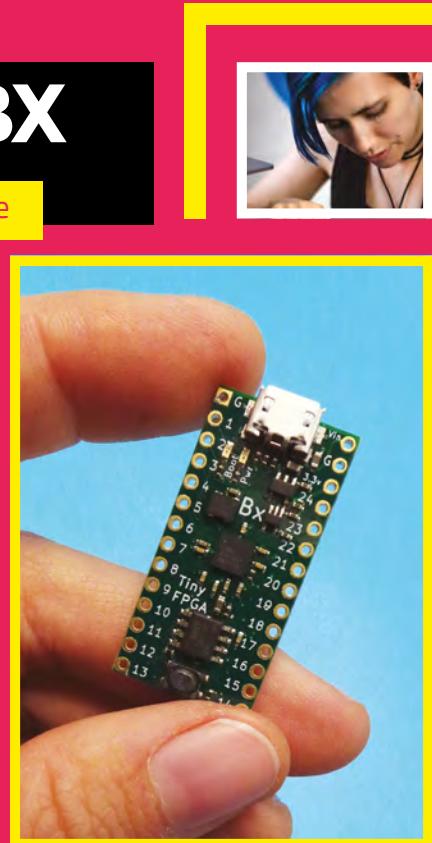
It's part of a family, and you can program the TinyFPGA B-series boards with Python, which makes it fairly accessible to software neophytes like myself. And you can put down that JTAG programmer – it comes with a USB bootloader. Use the open-source IceStorm toolchain or Lattice iCEcube2 design software to build tiny synthesizers and more. □

## BEAGLEWIRE

Open-source hardware and an open-source tool chain

**I**f you already have a BeagleBone, you can upgrade it with FPGA functionality using the BeagleWire.

Available from CrowdSupply, this smart purple cape doesn't work alone, but brings advanced functionality to your favourite platform. And you can keep on building from there – BeagleWire itself is expandable, with an embarrassingly large amount of available GPIO. This includes four ports for the Seeed Grove system, four for Digilent's PMOD peripherals, and BeagleBoard's twin 40-pin breakouts. Of course, there are a few programmable LEDs and push-buttons, too!



Once you discover a configuration you love, you can even customise the open-source BeagleWire itself: just download the KiCAD files from designer Michael Welling's GitHub page. It works with the open-source IceStorm FPGA toolchain, too!

BeagleWire runs on the Lattice iCE40HX4K chip, which is the high-performance version, compared to the low-power LP version on the TinyFPGA BX. It'll set you back \$85 on CrowdSupply. □

# ARTIFICIAL INTELLIGENCE

Hardware that thinks for itself

**D**epending on whom you ask, artificial intelligence is either a beautiful and terrifying dream or a bunch of hype about algorithms.

The difference is one of scope: strong AI, or artificial general intelligence (AGI), refers to machines that can mimic the human mind's abilities in a comparable variety of tasks. This is what sells movie tickets, and it's still out of reach... as far as we know.

What we do have is application-specific AI: trained neural nets that use layers of logic nodes to detect specific triggers, feeding that information in a cascade to other nodes, and finally making a decision about the input. Nets with multiple 'hidden' layers are known as deep neural nets. The classic example involves identifying handwritten numbers, and there are public datasets for this (see MNIST), as well as for classifying animals, emotions, or food.

If you'd like to learn more, I recommend YouTube videos by Siraj Raval (Sirajology) or Grant Sanderson (3blue1brown).

While some developers turn to FPGAs to make their AI applications run faster, others are creating new algorithms to speed up the process on traditional hardware: CPUs and/or GPUs. These boards are bringing the future to us...

## AIY VISION KIT - GOOGLE

I'm a huge fan of Google's new DIY AI kits! They blend elegant, folded cardboard enclosures (fun! recyclable!) with the latest tech. The kits deliver plenty of complexity without overwhelming you with options. Thorough and approachable, the tutorials walk you through assembly and introduce inspiring demo apps. These are written in Python.

I do think the default Joy Detection demo needs a bit of tweaking. When it sees a face, it assigns 'joy points' based on the person's expression. When the person moves out of frame, those points slowly deplete until it reaches Maximum Sadness! Perhaps this could be a fun programming challenge.

Since the Vision Kit isn't attached firmly to its enclosure, it's easy to repackaging. Thanks to the longish cables, I was able to turn mine into a robotic owl – my new mascot, Archimedes. I added a pan/tilt motor gimbal, too, which gives him some mobility. (I haven't yet been able to mesh the servo demo with the Joy Detector code, so I used an external Arduino for that; seasoned programmers will probably have an easier time.)

Bringing AI to the masses



Both AIY kits run on the Raspberry Pi Zero W, which has WiFi and Bluetooth capabilities. However, the Vision Kit doesn't require WiFi to run, which makes it a great choice for projects that you'll be travelling with. There are also a few GPIO pins exposed on the custom Bonnet, making hardware mods reasonably simple. (Not sure what a Bonnet is? It's like a HAT for a full-size Pi!)

As a side note, I'm stoked about this recent cardboard-and-electronics trend. Nintendo's Labo kit provides a creative physical medium for kids who are into gaming, Seeed's RePhone kit brings fun to cellular IoT, and Otherlab's Apsara drone is designed to compost away after delivering medicine to remote areas.

...The future is cool. □



# MATRIX CREATOR

Create a home brew assistant



**MATRIX** has come out with a couple of boards that are compatible with Google Assistant, Amazon Alexa, and

**more.** It's a solid choice if you've been thinking of building your own pet conversational AI.

The Creator's eight MEMS microphones will pick up directional audio. The board boasts a large ring of 35 RGBW LEDs – a stylish choice, since the white channel enables you to program pastel colours. You can use those to indicate its orientation, since it also features a 9-axis IMU with 3D accelerometer, gyroscope, and magnetometer. Temperature, humidity, and altitude, infrared and UV sensing, an NFC reader... it might be faster to list what this thing doesn't have. It can also transmit IR, so you can use it as a remote to automatically control your media systems.

Of course, all that makes it quite large. Its smaller sibling, the MATRIX



Voice, has an optional ESP32, which can be programmed using a Pi and then disconnected to run independently. The Creator will run you about \$100, while the Voice with ESP32 is \$65.

This one is also a sneaky entry for the FPGA category! It's equipped with a Xilinx Spartan 6 XC6SLX4 that should give you something extra to play with. For the future, I'd like to see more examples using privacy-focused tools like Mycroft and/or Snips.ai, or offline options like PocketSphinx. □

# MOVIDIUS NEURAL COMPUTE STICK (INTEL)

Building a virtual brain



If you really want to dig in and get your hands dirty, the Neural Compute Stick is a solid option for the code-competent. Shaped like a beefy USB drive, it can store trained models – enabling you to develop a neural net (such as a cat/dog breed detector), then plug it into a Raspberry Pi and start identifying things immediately.

As for training, I attended a session that involved a few hours of importing and manipulating open datasets in a Jupyter notebook, accessed from Intel's servers, running TensorFlow. The process was a bit intimidating for me, as I'm more of a hardware kid... but this is true of training any AI from scratch.

Still, it was fascinating, and if you want to really come to grips with neural nets, Movidius gives you a playground that you can use with advanced hardware projects. My favourite example is Clean Water AI, a project by Peter Ma, which uses a camera to detect various types of bacteria and can test water quality without chemical strips. □

# MYCROFT MK II

Keeping your data off the cloud



**Speaking of Mycroft, they've just released the second iteration of their own hardware device.** They're the

'good guys' of the companion AI market, with a focus on open-source technology, privacy, and empowering user controls. You can build your own interface using a Raspberry Pi, or pick up one of these gadgets, which are engineered for sleek performance.

Its six microphones, powered by Aware, deliver excellent audio recognition at a distance. And the built-in screen provides a friendly smile with useful graphics.

Get the DIY kit for \$109 on Indiegogo, or the camera version (with mechanical shutter) for \$189. Want to mod it? No problem – update files, I/O, and software via the USB and SD card slots. □



# BEST OF THE REST

The great bits of tech that defy categories



**Here's a grab bag of delightful new tools that you shouldn't miss!**

Here, I've picked out a couple of genre-specific recommendations for music and neuroscience. One of the hallmarks of hardware hacking is creatively using objects beyond their intended purpose, but sometimes it just helps to have the right tool for the job. What can I say? Music hardware nerds know how to build good music hardware.

I've also put in a couple of newer connectivity tools. With IoT coming into full bloom, it's worth knowing that there's more than WiFi and Bluetooth out there. Besides these two, there are other new tools for connecting with the CAN bus on your car (or industrial machinery), new options for mesh networking, new ways of transmitting data through invisibly blinking lights (see my Tomu recommendation). We live in a world of interlocking and interfering signals, and it's useful to be literate.



## HOLOGRAM NOVA

Makers, phone home



**Hologram is bringing cellular connectivity to maker boards everywhere.**

You can use it with the Onion Omega 2, and they've even gotten in on the conference badge scene with the official EMF Camp badge (a functioning cell phone!).

I expect Hologram to become ubiquitous, and not just because they give out samples like candy. (That doesn't hurt, though.)

The Nova is Hologram's USB modem, which plugs easily into a Raspberry Pi or other computer. Its cellular functionality comes from a u-blox SARA chip, and it comes in three flavours: global 2G/3G, LTE-M, and NB-IoT (that's the new narrow-band IoT standard). Just insert one of Hologram's SIM cards and your project has global connectivity. It automatically switches carriers to use the best available signal.

You can order these in bulk quantities, but if the Nova's current form doesn't suit your product, it's also open-source! Hit the GitHub and you can start producing your own. But as it is, it comes with FCC certification: a nice leg up for connected hardware startups. Their pay-as-you-go model doesn't require a contract, either: if you stop using data, you stop paying for it.

Since I have to mention blockchain somewhere, I'll do it here. Hologram is a great option for asset tracking, which is a practical use for blockchain technology



(given its emphasis on verifiability). Also, I recently built a portable console that accesses and prints documents from the Interplanetary File System – a blockchain-based alternative web, used to maintain permanent and secure records between peers – and I can't wait to upgrade it from WiFi to cellular using the Nova.

The Nova comes in at \$69, a SIM card is \$5 (unless you get the free Pilot plan), and data is less than \$1 per megabyte. For global sensor intelligence, that is a very good deal. □



## NEUROTINKER NEUROBYTES

Making computers nervous



## MKR NB 1500 – ARDUINO

Getting data where others can't



Once it's available, I expect that the MKR NB 1500 will be many makers' first introduction to narrow-band IoT.

This is a new communication system designed for connected devices, such as sensors for smart cities. It uses 4G cellular networks, but for very small amounts of data.

We've seen other attempts to address the needs of connected sensors: Narrow band-IoT is a bit more responsive than LoRa, which usually requires you to set up your own network and has rate limitations in Europe. Perhaps this new technology will catch on faster.

**N**euroBytes are a beautiful tool for teaching neuroscience, and simultaneously a bit of electronics (who says you can't have both)? The

system includes a laser-cut, articulated leg that can model reflexes, as well as a 'Rod' photoreceptor for building eyes. Looking for an R/C car with personality? Explore the 'Insecure' or 'Timid' Neurobuggy projects.

Design genius Zach Fredin is worth a follow, as he regularly builds gorgeous tiny electronics on the side. You'll also see him testing new designs, such as wooden pieces that snap onto ping-pong balls to create elegant joints.

With an average price point around \$100, these aren't the most affordable kits on the market, but they're a uniquely tactile way to experience the nervous system. □

The NB 1500 board shares the Vidor's narrow MKR form factor (first seen in the WiFi-equipped MKR 1000), which is Arduino's new design direction. It'll be interesting to see whether the community continues to embrace the original Arduino form factor (still the hardware lingua franca for microcontrollers and shields), versus the MKR shape and Adafruit's Feather standard. □

## BELA MINI

Pocket-sized music powerhouse

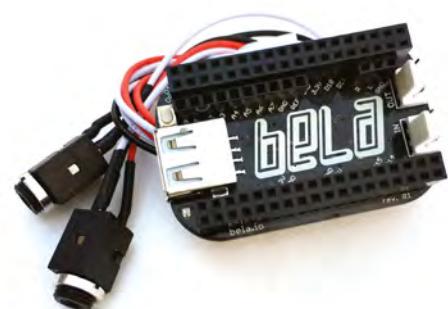


**T**he Bela Mini is a cape for the PocketBeagle – a miniaturised version of the BeagleBone Black. I'm not a huge music-tech buff, but I have friends who are, and they're pretty excited about the Bela. Its selling points are low-latency audio and lots of processing power.

There's a full-sized version as well, but this one comes in an irresistible snack size.

There's no native wireless connectivity: to set up your project, you plug the PocketBeagle into your computer, then program it (and Bela Mini) in your browser. You can run Pure Data patches on it, connect custom sensors, and easily manipulate sounds. That includes triggering samples, applying effects, panning between left and right channels, and more. Hello, custom guitar pedal!

The Bela producers have also prototyped a Seeed Grove add-on, which can be stacked atop both boards, and I hope they bring this out for the public. For now, you can get the standalone Bela Mini cape (with a couple of 3.5 mm audio adapters) for £60; for double that, get a full kit with a PocketBeagle and pre-loaded SD card. □



# GEMMA

When you need to wear your electronics

# A

**w yeah!** I get to talk about one of my favourite new boards, and I'm picking the Gemma M0. It's slightly older than 2018, but who's counting?

Adafruit has recently been releasing new boards based on the ATSAMD21 and ATSAMD51 – ARM Cortex-based microcontroller chips that pack a macro punch.

The Circuit Playground Express (\$25) is perhaps the best-known, and it's a great introductory board: ten RGB LEDs in a ring; buzzer, microphone, temperature sensor... tons of functionality in a medallion-sized device.

The Trinket M0 (\$9) is an upgraded version of the ATtiny85-based Trinket – it remains a small, rectangular board with regular-size breakout pins.

The Gemma M0 (\$10), likewise, is an upgrade to the original Gemma. All three are based on the ATSAMD21 Cortex M0 chip; they are affordable, and share a beautiful matte black finish. (It matters!)

I've singled out the Gemma because it is one of the most perfect boards on the market for wearables. It also happens to be a great board sans wireless connectivity.

The Gemma M0 is dependable and comes with a solid feature list:

Like the Circuit Playground Express, it has large plated holes that work with alligator clips or conductive thread.

These two also share a JST connector for LiPo batteries. All the best things in life are rechargeable.

Like the Trinket M0, the Gemma comes loaded with excellent example code that demonstrates capacitive touch, analogue voltage output, and more.

The Trinket and Gemma are both pretty small; one's a circle and one is a rectangle, but the max width for each is about the same, despite the Trinket's smaller pins.

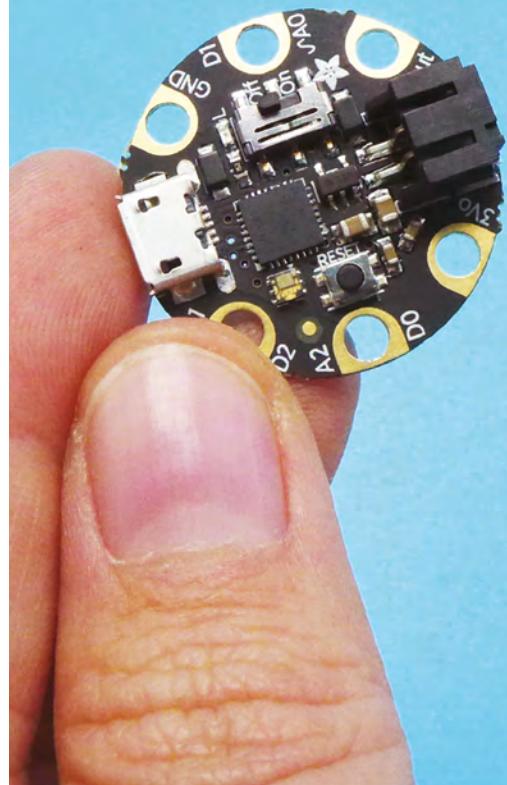
All three boards can run CircuitPython – Adafruit's branch of MicroPython, which is itself a stripped-down branch of Python for microcontrollers.

One of my favourite features is the power switch. I'm not kidding. It's lovely to be able to turn off a project without unplugging it every time! (One of my gripes with the CPX, which also uses a JST battery connector: I have to pry it out with my fingernails anytime I'm not on USB power.) Only the Gemma has this.

All right, let's talk about CircuitPython. This is a blessing for all makers. First of all, many of the software devs who are taking the plunge into hardware are already familiar with Python. (I was writing simple IRC bots in Python before I ever touched an Arduino.) But most importantly, it gets saved directly to the board with no extra compiling step.

## QUICK CODING

This is big, because it means that you can build a gorgeous little kinetic sculpture, leave it on a shelf for eight years, come back, plug it in, and read the code off it as easily as plugging in a USB cable. No



digging around in ancient folders with arcane numbering systems on dusty machines, desperately psychoanalysing your previous selves. Just open the drive and double-click the main.py file. I can't overstate how marvellous this is! You can use any computer to update your code, even if it's the last stretch of a hackathon and your adapter has died. You are free.

It's also a little faster to upload code; I won't ignore that bonus. But the saving thing is huge!

Now that we're familiar with CircuitPython, how do we use it? Like the micro:bit, Gemma M0 can be programmed using the Mu editor, which has a built-in serial console for easy debugging. But if GUIs aren't cool enough for you, you can bring up a console in the terminal. (The .py file can be edited with any text editor, including vim.)

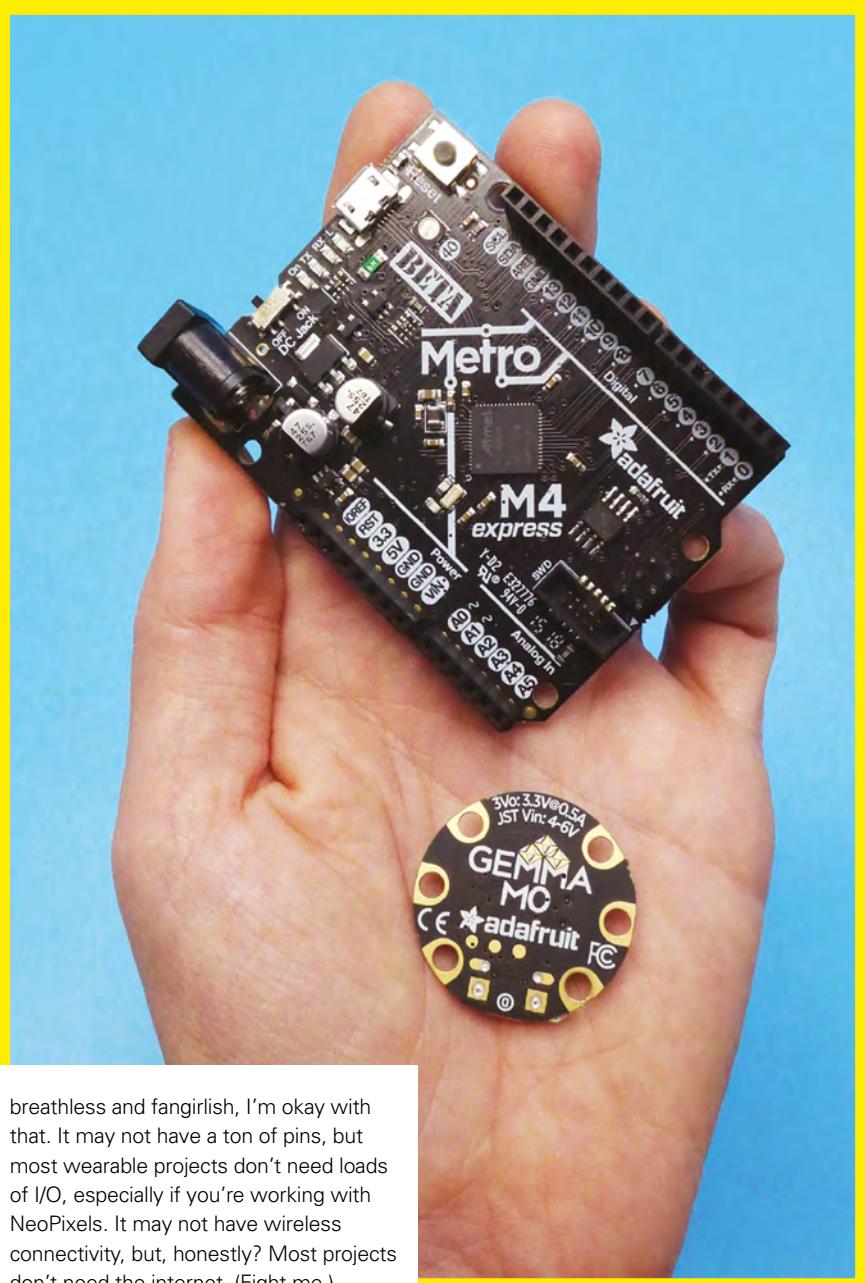
Remember that beautiful demo code that comes pre-loaded on the board? It's an excellent built-in reference, and I recommend saving it under another name before modifying it. You can use it to create all kinds of applications. I built an LED-equipped mask for lucid dream induction, using little more than that example code.

And how do you find out whether or not your code is working? The Gemma's built-in RGB LED (an APA102 'DotStar') flashes a code to tell you what's going on. Either it goes solid green, or it flashes a colour sequence that you can compare with a table in the docs. For example, my favourite cyan colour indicates a syntax error, and green is for misapplied indentations. That's followed by a sequence that tells you which line of code to check.

### SNAKE CHARMING

I should note that there's also a built-in LED on pin 13, because some traditions are worth keeping. I should also note that, yes, you can still run Arduino on it. But this newfangled CircuitPython thing has me seriously questioning my loyalties...

In summary, there's a lot to love about this board, and if my tone seems a little



breathless and fangirlish, I'm okay with that. It may not have a ton of pins, but most wearable projects don't need loads of I/O, especially if you're working with NeoPixels. It may not have wireless connectivity, but, honestly? Most projects don't need the internet. (Fight me.)

...Just kidding. Go check out the product page and see if you agree; I'd love to hear what other people think about this little heavy lifter. If you're looking for something more Uno-like, check out the Metro M4 Express (\$27.50), which is the bigger sibling in this family, based on the ATSAMD51. Have a look at the Feather M0, too, which of course uses Adafruit's Feather standard. And finally, whatever you go with, have fun and hack on! □



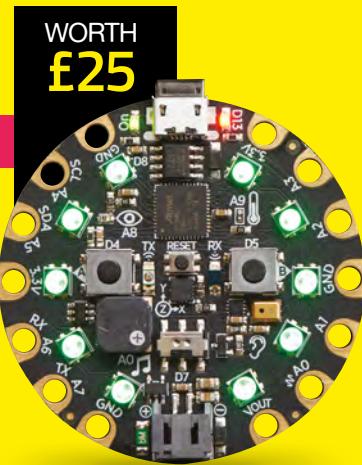


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# HACKY RACERS

Who says you have to be a millionaire or a petrolhead to have a go at motor racing?

By Jenny List

**T**here are many things that define the culture of our community, be they bottles of Club-Mate in a hackspace fridge, 3D-printed Benchy printer calibration models on every surface, or the Badgelife electronic wearable scene we covered in a previous issue. Just occasionally we are privileged enough to be present at the genesis of a new one, and such a moment came earlier in the year with the birth of a community of people building and racing small, and slightly comedic, electric vehicles here in the UK. The Hacky Racers series has just had an astoundingly successful first public outing at the Electromagnetic Field hacker camp this summer.

In the USA there has been, for some years, a small electric vehicle racing series in our community. The Power Racing series has its roots in a Chicago hackspace, and its vehicles are essentially motorised versions of children's ride-on



**Above** Mark Mellors's Rule Zero is one of several converted mobility scooters on the grid, fitted with a fire engine body. It's a Hitchin fire engine because he hails from Hitchin Hackspace

toys. No doubt many of us on this side of the pond have looked enviously at our transatlantic friends and wished we could have a go, but for it to come together here required a catalyst. That came in the form of a post on the Power Racing forum from rLab's Keegan Neave, musing about a British series, and it arrived on fertile ground populated by a crossover of Robot Wars competitors with no TV show to build for, and hackspace members building hacker camp transport after being heavily influenced by Hitchin Hackspace's Bighak, TOG Dublin's motorised duck, and the German machines using hoverboard motors at SHA2017. A community formed, and in the summer we brought our machines along to a first meeting on a farm in the West Country, to see whether we'd created something worth pursuing.

The Scrumpy Cup, as that first meeting was called, was very much a private affair at which the object was to shake down



**Above** ◇  
A Power Racing grid  
in Detroit, 2018

**Credit**  
Pete Prodoehl,  
CC-BY 3.0

**Right** ◇  
The Scrumpy Cup  
didn't have a cup as  
such, but it did have  
a barn to serve as the  
pit lane for the event.  
Here you see early  
versions of many  
of the machines  
that would go on to  
appear at EMF Camp



our new vehicles, learn what they were capable of, and lay the foundations of what would become the public series. There were many familiar faces from other parts of our community there, but this was the first time we had all come together as a group. We raced on a hard circuit, we raced on mixed soft and hard ground, we did time and manoeuvrability trials, and we raced at night. We had a nascent racing series, and arrangements were made behind the scenes to bring it to the then-upcoming Electromagnetic Field hacker camp at Eastnor in Herefordshire, where we unveiled it for the first time to our public.

## ON YOUR MARKS

So just what is a Hacky Racer? There is a comprehensive rules document derived from the Power Racing rules on the Hacky Racers website but, in short, it's a vehicle of less than 1500 mm length and 900 mm width, driven by one or more electric motors, and with a body derived from a toy or in the spirit of a toy. There are plenty of rules dealing with budgets and safety, and rather than restrict the choice of motor, the power is restricted by specifying maximum current for a given voltage by means of a particular fuse. Within that framework there is an astounding flexibility, and on our first →

## The Dustbin 7

Rory Mangels is somebody you may be familiar with through the *Robot Wars* Team Nuts, so you would expect that when he turned his attention to Hacky Racers it would result in something interesting. The chassis is a welded steel affair with what look like mobility buggy wheels and tyres, and it has the usual 2 kW Chinese scooter motor and controller, with LiPo batteries.

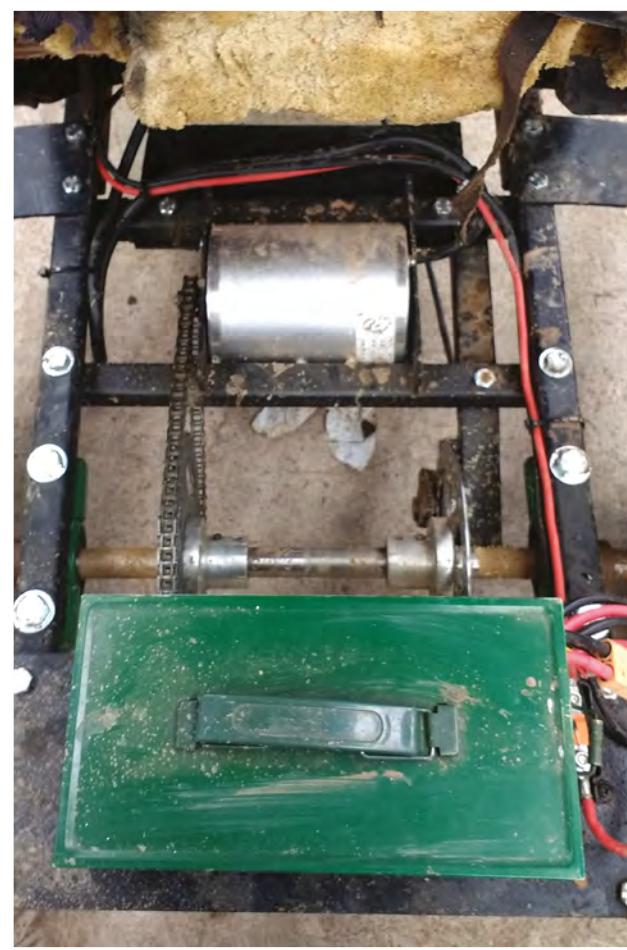
He's done a beautiful job on the bodywork, with a vintage car feel provided by bodywork fashioned from a plastic waste bin, and the seat from a 1960s Triumph Herald. The car appears in more than one of the pictures we've chosen for this piece, and is definitely one to beat if you wish to become a serious contender.





### Trikemare before Christmas

The Trikemare from Alex Shakespeare is a scratch-built three-wheeler with an unusual design in the form of a tricycle with the single wheel at the rear. It has the same 2kW scooter motor as four-wheelers such as Rule Zero, with a chain drive to a mini-moto rear wheel. At the front it has go-kart stub axles and steering. The motor is mounted using laser-cut plywood brackets which failed at the Scrumpy Cup but which proved reliable in their revised version fielded at EMF Camp. The result is a powerful, manoeuvrable, and extremely competitive vehicle.



**Left** The motor, chain drive, and battery box on Rory Mangles's Dustbin 7

grids there was definitely a wide variety of motor, battery, and chassis configurations.

We know exactly where this is going as you are reading this: you now want to build one yourself. Fortunately this is a very achievable aim, and there are a variety of suggestions to get you started. You need to think first about your chassis and running gear, then your motor and drive system and, once you have those, you should be able to attach whatever body you consider most appropriate.

The easiest way to solve your chassis problem is to use one off-the-shelf. One of the larger mobility scooters is a popular choice, but we've also seen small golf buggies and pedal go-karts pressed into service, and, when one of the originators of those hacker camp beer

crates heard about the series, the iconic German Bobby Car child's toy.

#### BUYING IN

The advantage of using an off-the-shelf chassis is clear. You have wheels, suspension, and steering ready-made,

within the capabilities of a well-equipped workshop or hackspace. The motors however are another matter, because if a donor is already motorised, it is unlikely that it will have the gearing required to give it a competitive top speed. As an example, those competitors who used

golf buggies found that, while they had the required power, they were significantly slower than others with custom motor configurations.

Building a chassis is a more challenging route, but lends the

advantage of giving you complete control over your creation. A welded steel box section seems to be the preferred choice here, but one machine made clever use of welding together scrap bicycles. Beyond that, there is nothing to stop you using

There is nothing to stop you using almost anything rigid enough as a chassis

and in some cases you can even use the same motors, batteries, and drive electronics. There are often some tasks to be performed in modifying the geometry of the vehicle, for example lowering the seat of a mobility scooter, but these are usually

almost anything rigid enough as a chassis; with clever use of plywood or fibreglass, something truly unexpected could emerge. The self-build chassis maker must furnish their own running gear, but fortunately the world of quads and mini-motos has plenty of suitable suspension and other components.

### POWER UP

The motors and drive are a surprisingly straightforward part of the build, thanks to the Chinese motorised scooter and hoverboard industries. There is a ready supply of both motors and controllers that would have been undreamed-of only a few years ago, and what would once have been one of the most expensive components is now an extremely affordable off-the-shelf purchase.

The most popular choice appeared to be the 2 kW brushless electric scooter motors with chain drive, but as our German entrants showed us, the in-wheel hoverboard motors

can also be extremely competitive. The batteries are an area in which the choice of a large lithium-polymer pack is not a difficult one to make. However, there are a significant number of safety rules associated with these batteries because they present a fire risk, so they must be contained within appropriate fireproof housings. The ubiquitous ammunition box is a feature of all racers for this purpose.

How your finished machine looks is completely in your hands, though. The previous paragraphs have made a few suggestions based upon what appeared at EMF and the Scrumpy Cup, but we know that this is a series that has a way to evolve. Think for a minute about *Robot Wars* and compare a heavyweight from 1998 with one from 2017: they are an entirely different class of competitor. The coming years will see an evolutionary process in the world of Hacky Racers as new ideas and new components arrive. It will get ever more fun and interesting and, due to the careful budget and power constraints, we hope it won't lose its accessible edge. Get busy building your Hacky Racer now! □

**Below** Racing action at EMF Camp



### The Ottercar and Ottermobile

Niklas Fauth and Jan Henrik are a pair of German hardware hackers who, among many other projects, have done a lot of work on reverse-engineering hoverboard motors. Theirs was the motorised beer crate that had British hacker camp attendees so envious in 2017. They heard about Hacky Racers only ten days before EMF Camp, and within three days had come up with a pair of machines that turned out to be extremely competitive.

The Bobby Car is an iconic German toy, a small but extremely robust child's sit-on car. There is a downhill racing scene for these machines in Germany, so they are track-proven, and what Jan has done with the Ottercar is attach their trademark hoverboard motors in place of the original wheels.

The result is a very compact and extremely quick vehicle. To meet the Hacky Racer rules it has an external steel framework to provide some bumpers, but there is no actual reason for it to be there, beyond that rule.

Meanwhile, Niklas has taken a Kettler pedal trike, lengthened it, and replaced all three wheels with hoverboard ones. Both machines are fast and competitive, and have taken a completely different tack from their British counterparts. We hope that Hacky Racers will spread to other European countries, and the diversity this will spawn will make for a far more interesting grid than we'd see if only Brits were involved.



# DAVE HAKKENS'S Precious Plastic Machines

Join the fight against plastic pollution!



**Cameron Norris**

@cameronsnorris

Cameron is a technology and communications specialist, passionate about the use of open-source hardware for social innovation.

**P**recious Plastic is a global community of makers working towards a solution to plastic pollution.

Hundreds of people from around the world have built these open-source machines to recycle waste plastic into unique products and building materials.

According to a report by the Ellen MacArthur Foundation, just five per cent of the 311 million tons of plastic produced every year is effectively recycled. Around 40 per cent of this plastic ends up in landfills, and over 30 per cent goes on to pollute the planet's delicate ecosystems, including the world's oceans.

Making new plastic has become even less expensive than recycling, unbelievably, due in no small part to a global excess supply of oil. Without a market for these recycled materials, even putting waste plastic into your recycling bin doesn't necessarily mean that it will be recycled, as it often ends up in a landfill anyway. This caught the attention of Dutch designer Dave Hakkens, who, for his

graduation project at Design Academy Eindhoven, decided to do something about it.

Dave began developing a series of low-tech machines to move plastic recycling from expensive, large, industrial-scale factories, and into the hands of enthusiastic makers looking for new, more environmentally friendly materials to work with. The resulting set of open-source, easy-to-build machines enables almost anyone, anywhere, to contribute to plastic recycling, while opening up new opportunities for economic development and job creation. Since launching the Precious Plastic project in 2013, over 200 plastic recycling workspaces have been set up, and new ones are opening up around the world every week.

The complete kit consists of four main machines constructed from sheet metal and scrap parts: a shredder for creating waste plastic flake, an extrusion machine for processing the plastic flake into 3D printer filament and granulated plastic, an injection moulding machine for the production of very precise objects, and finally a compression oven for



## CLOSING THE LOOP

"We want to show the world the incredible opportunities of plastic waste in order to eliminate plastic pollution, reducing the demand for new virgin plastic, and closing its materials loop, while creating better livelihoods for people around the world. Precious Plastic is, above all, a cultural tool to change the way society perceives plastic."

**Dave Hakkens**

making large and durable objects. Dave's website, [preciousplastic.com](http://preciousplastic.com), acts as the central hub from which his community of over 100 000 participants organise and educate themselves. The page for each machine includes all the details you need to build one yourself. There's also information on how to use the recycled plastic to make everything from building materials and household items, to phone cases and even cheap and cheerful jewellery.

Finally, the site's global online marketplace, known as the 'Bazar', helps community members to generate income through their plastic recycling activities, by selling recycled products and machine parts. One example is Koun (which in Arabic translates as 'either'), a social enterprise based in Morocco which employs young people to collect and transform plastic waste into products, which are sold through the online Bazar and their bricks-and-mortar store in Casablanca.

## CREATE NEW PRODUCTS

Koun collects raw material from local schools, businesses, and the streets of Casablanca's Medina itself, which is then cleaned and processed before being sent to one of three workshops to make furniture, clothing, or stationery.

"What makes Koun special is their ability to merge Precious Plastic with traditional Moroccan crafts, by combining plastic with metal, wood, and textiles in unique ways," says Dave.

So far, Koun estimates that around 22 000 kilograms of waste material has been recycled into new products. "Even though they're still far from fully covering their expenses with sales, we believe they're on the right path to make the project financially sustainable in the near future."

On 26 May 2018, the FAMAE Foundation awarded 300 000 euros to the Precious Plastic project, to further develop their machines. The plan for Precious Plastic Version 4, as Dave describes it, includes the development of semi-industrial systems that are capable of recycling plastic in much larger quantities than is currently achievable with the existing open-source machines. Dave also plans to welcome 45 volunteers from around the world to work on the project from his new warehouse in the centre of Eindhoven. Let's take a look at the machines. →

## OPEN FOR EVERYONE

"We share everything open-source for anyone to benefit from. This means that all the knowledge, know-how, processes, methodologies, and tools are available online, for free at all times. This open-source philosophy is at the core of the project and shapes most decisions within the team. We believe that 'collaboration' is stronger than 'competition', and that the plastic problem can only be solved collectively."

**Precious Plastic Team**



HackSpace

**Left ↗**  
The complete set of Precious Plastic machines, created by Dutch designer Dave Hakkens

**Image Credits**  
Precious Plastic  
CC BY-SA

# DAVE HAKKENS'S Shredder Machine



Above ♦  
Let's keep this  
fantastic resource  
in circulation

## HEATING PLASTIC

There are two main material categories in the world of plastics: thermoplastic and thermoset. Thermoplastic materials can be melted and reformed multiple times, whereas thermoset materials can melt and take shape only once. After they have solidified, they stay solid forever. In the thermosetting process, a chemical reaction occurs that is irreversible. Thankfully, thermoplastic materials make up to 90% of global production.

**T**he industrial process to reclaim waste plastic typically starts with manually dividing the collected material by type and colour. The most common waste plastic laying around your home is probably PET (polyethylene terephthalate) used for drinks bottles, and HDPE (high-density polyethylene) used to produce household detergent and shampoo bottles.

Once divided by type and colour, the waste plastic is passed through a slow-moving shredder to produce chips of various irregular sizes. The resulting chips are washed thoroughly to remove contaminants, such as chemical residue, food and labels, and then passed through a second machine called a granulator. The granulator runs at a higher speed than the shredder, and is designed to produce flake feedstock of a specific size for recycling into new products. According to Dave, the going rate for cleaned flake feedstock is eight to ten times higher than unshredded plastic, and 10kg of clear PET flake typically sells for around £70 on the community Bazar.

Although the Precious Plastic Shredder machine is capable of producing flake feedstock directly from unprocessed plastic waste without the need for a separate granulator, Dave suggests breaking up bigger plastic objects into smaller chunks with hand tools as a precautionary measure, to prevent the machine from jamming.



The bill of materials cost for the Shredder machine sits at around £200, depending on your location, which is remarkably good when compared to prefabricated models of a similar specification. Commercial shredders typically start at around £2000 if you're willing to have one shipped directly from China, and cost significantly more if purchased from Europe or the United States.

## SHRED THAT PLASTIC!

While exploring the documentation, you may notice that although detailed CAD drawings are provided for the cutting blade design, only a loose framework is suggested for the machine's overall construction.

There is a good reason for this. The Shredder's loose design can be adapted for any motor with a power of +/- 2 kW and output speed of +/- 70 rpm, which means the size and shape of the motor selected may vary wildly from one build to the next.

The output size of the flakes can be changed by altering the size of the sieve placed within the machine to act as a filter. "Different sizes of flakes will give a different pattern; smaller flakes melt easier, but take longer to shred," explains Dave.

When you finish working with the shredder, make sure to store away the shredded plastic or the next person using the shredder won't know what plastic type is in the bucket. Now you're ready to start producing new products!

Left ♦  
Start shredding with  
Dave Hakkens's  
open-source  
Shredder machine

# DAVE HAKKENS'S Extrusion machine

**T**he Extrusion machine is used to process flake feedstock into a continuous plastic thread which, in turn, can be used to make new raw materials, such as granulated plastic and 3D printer filament, or even spun around moulds to form unique products.

"Technically, if you have enough plastic and a well-streamlined process, you could be recycling 24/7," explains Dave.

Overall, the process is very straightforward and easy to understand, which makes it great for educational and demonstration purposes. Flake feedstock is inserted into the hopper and then pushed along a narrow steel barrel by an extrusion screw, which moves the material towards band heaters, positioned uniformly along the length of the barrel. Once the flake feedstock reaches 130 to 170°C, the molten plastic is pushed through an extrusion nozzle to form a single continuous thread.



## SELL YOUR RECYCLED PRODUCTS

If working with steel moulds, the molten thread emerging from the nozzle is repeatedly wrapped around the mould until the desired effect is achieved and the new product is formed. Dave says that an important point to keep in mind when using this technique is always to design moulds with convex walls, as this makes it much easier to release the plastic product from the mould without damaging it. Mastering this process generally requires a bit of patience and practice, but anyone should be able to make unique and interesting objects after a few attempts.

The latest documentation suggests using a wood auger to transport flake feedstock down the barrel, but commercial extrusion machines use purpose-built reciprocating screws. Theoretically, the mechanical energy generated by these screws rotating inside of the barrel reduces the amount of electrical energy consumed by the band heaters to melt the plastic, resulting in a more energy-efficient system. However, the added friction requires a more powerful (and likely more expensive) motor, which is why the use of an industrial extrusion screw is mentioned as an optional upgrade, rather than a base design.

Similar to the Shredder, the total bill of materials cost for the machine sits at around £200, depending on your location. "We used a 100rpm 12V DC motor, digital speed controller, and 12V DC power supply designed for high wattage LED installations," explains Simon Clark, who travelled to Haiti in 2016 to help his cousin Sarah set up a community-based Precious Plastic workshop. "For the body of the extruder, we started with a stainless pipe, cut out the hopper hole, and welded on plates for the hopper to attach to," he says. "The extruder build was completed on the second last day of the trip." →

**Left** Make plastic thread with Dave Hakkens's open-source Extrusion machine

## MAKING RAINBOWS

The Extrusion machine is also capable of blending different coloured plastics to form new colours. For example, if you mix blue and yellow plastic, you create a homogeneous green material, or you can create colour gradients by gradually adding feedstock of a different colour while the machine is running.

**Below** A recycled phone cover looks great and saves the planet



# DAVE HAKKENS'S Injection Machine

**I**njection moulding is one of the most commonly used methods to mass-produce plastic products. It is very similar to extrusion moulding, with the main difference being the way the molten plastic is distributed into the mould. The industrial process typically involves melting granulated plastic inside the barrel of an injection machine, which is then pushed into a temperature-controlled split mould at high pressure by an internal reciprocating screw. This process is the most common modern method of manufacturing plastic parts, and can be used to make everything from small kitchen items and bathroom appliances to outdoor cabinets, sheds, and large playground items for children.

In comparison, Dave's Injection machine is designed to produce small batches of very precise, detailed objects, such as phone cases or desktop toys. First, flake feedstock is fed into the barrel and then heated for 15–20 minutes. Once the plastic in the barrel reaches a molten state, pressure is applied using a steel plunger, operated by a hand-powered lever.

Once the plunger has forced the molten plastic into the mould, the mould can be carefully removed and cooled before opening. "The process in itself is tightly connected with moulds and mould-making. If you have a precise mould, you can create beautiful products in a matter of minutes and start a little local production," says Dave. However, unlike the Extrusion machine, which uses a reciprocating screw to mix the flake feedstock in the barrel, the Injection machine cannot homogeneously blend different coloured plastics. "The output colour is often unpredictable when mixing colours in the barrel, allowing for surprising patterns that can add to the beauty of your products," Dave explains. Complex moulds can be made using a CNC mill or aluminium foundry and a bit of welding.

**Below** Create new products with Dave Hakkens's open-source Injection machine



## IN THE BEGINNING...

The first plunger-style injection moulding machine was patented in 1872 by American inventor John Wesley Hyatt and his brother Isaiah. John was also responsible for the development of celluloid, the first synthetic plastic. Celluloid is best known as the material used for the thin sheets of film used in early photography and cinematography, but it also replaced ivory as the raw material in the billiard-ball manufacturing industry.

## A PRECIOUS MATERIAL

At around £120 (depending on your location), the total bill of materials cost for the Injection machine is around 40% less than the Shredder or Extrusion machine. This is mostly thanks to the system's manual operation, which does not require a motor. It is worth noting, however, that this does not include the cost of fabricating or purchasing a mould.

Optional upgrades include insulating the barrel using ceramic wool, and a perforated steel sheet to reduce heat transfer with the surrounding air, improving the energy efficiency of the entire system. "To create an efficient process, it is advisable to run the machine for a few hours once it is started. Don't start and stop the machine too often as the process will be very inefficient," says Dave.



**Right** Insulation can be used to improve the energy efficiency of the Injection machine

# DAVE HAKKENS'S Compression Machine

**C**ompression moulding is one of the original processing methods for manufacturing plastic parts, and was widely used in the bakery industry before plastic materials even existed.

Today, compression moulding is commonly used to manufacture car parts and household appliances. Polymer feedstock is directly placed into a heated mould cavity, and pressure (usually ranging from 800 to 2000psi) is applied by a hydraulically driven press, until the material has conformed to the shape of the mould. Throughout this process, heat and pressure are maintained until the polymer feedstock has been cured. While most commercial applications use only thermoset polymers, Dave's machine is designed to use recyclable thermoplastics, including HDPE.

## CRAFT UNIQUE PATTERNS

Dave's Compression machine uses an electric kitchen oven to heat flake feedstock for 30 to 40 minutes, before a car jack applies pressure to the molten material by pushing the mould against the ceiling of the oven. After a couple of minutes of applying pressure, the car jack can be released and the mould can be removed for cooling in air or water. Once the mould has cooled, it can be safely opened, enabling you to inspect your new product. If mixing different-coloured plastic flake, the Compression machine gives a mottled, flake-like look to plastic. This process is generally slower than extruding or injecting, but it allows for more ambitious products to be created. "This machine can also be used to create new raw materials, like big sheets of plastic," says Dave.



Overall, the Compression machine is simple to understand and very powerful, when properly mastered. It can be operated by a single person and can be used to easily create beautiful products, provided you have the right mould and materials. The bill of materials cost is comparable to the Injection machine (around £120, depending on your location).

If you want to speed up your rate of production, an optional upgrade is to move the compression area to the underside of the machine so the oven can be used to heat up another mould while the first is being compressed and another cooled. This way, the machine can run continuously.

"Besides being more productive and efficient, this upgrade makes the machine easier to build as you don't need to install the compression mechanism inside the oven," reveals Dave.

Precious Plastic isn't going to solve the problem of waste plastic by itself, but, as Dave said above, "Precious Plastic is, above all, a cultural tool to change the way society perceives plastic", and it's well on its way to achieving this goal. It's enabling makers not only to take plastic out of the waste system, but show just how beautiful waste products can become when they're treated with care and an artist's eye.

Don't forget that you can find out more, and apply to join Precious Plastic as a volunteer, by paying a visit to their site at [next.preciousplastic.com](http://next.preciousplastic.com). □

**Left**  
The Compression machine with optional upgrades to speed up production



**Above**  
The plastic can be moulded into almost any shape

## FIRST PLASTICS

The world's first plastics moulding company was founded by Alfred Critchlow, who emigrated to the US from England in 1843, before setting up the Pro Corporation in 1847. Alfred invented 'Florence compound', an early form of plastic made from shellac, wood fibre, and soot. The Pro Corporation moulded this compound into buttons, hairbrush handles, and ornamental cases for daguerreotypes – delicate images that result from the first commercially successful photographic process – using early compression machines.

HackSpace magazine meets...

# AL BULL HALFPENNY

Making is fun, and here's the man to prove it

**Y**outuber, maker, chef, and designer Alex Bull Halfpenny is a busy man. When he's not building daft things in his shed, he's creating Fools With Tools podcasts, sharing skills with the makers around the country and beyond. He's a great example of the self-taught maker, with a little bit of knowledge expanded through hours of breaking things to make unique creations (who among us doesn't want a voice-activated beer dispenser?).

We took the short trip to Al's Hack Shack, the shed that he built himself, to marvel at the suit of armour, the chainsaw on a stick, and the number and variety of things that his viewers have sent him in the post. →



Above □  
Workbench  
achievement  
unlocked. Other  
beers are available



**Above** ■  
This isn't the Health  
and Safety-approved  
method of eating  
an apple

**HackSpace** Thanks for having us over, Al. One obvious question, looking around at all this stuff is, where do all your tools come from?

**Al** A lot of them are just given to me. Anything in a green box is basically the stuff I bought: your bog-standard jigsaw, your bog-standard orbital sander; all the things your dad had. I did get a circular saw – they're really handy – and a big drill. Job's a good 'un. You can hang a picture, you can build a little table, that's it. And when I started talking to actual makers and craftsmen, they were like, "no, you need an angle grinder, you need a bench grinder." You need a drill-press – you can't drill a straight hole unless you've got a drill-press. Everyone was kind of donating their old stuff to me when they upgraded. "You can have my old pillar drill, I don't use it, and it's not heavy-duty enough." Or, telling me that I could have their old chop saw for £20.

**HS** That's amazing.

**Al** It's fantastic, and the more people I meet in the community, the more this is a recurring thing. People will say things like "I've got more tools than I need, it's a hobby. If it gives me an excuse to buy the next one, you take it off me, you make something, you pass it on to the next person." It's like a chain.

Everyone's got that attitude, it's great. On the podcast that I'm a part of, Fools With Tools, we've got loads of people in the same situation and they all say, "Oh, I really need this tool", and within seconds there'll be ten people popping up to say "I've got one, you can have it. Where do you live? I'll drop it off". We're starting to build this network across the UK of people helping out with tools.

If there are things that I don't need, I can take them down to the makerspace in Leeds; they're always desperate for tools that work. It's just this really nice, recycling, don't throw stuff away, fix it... I've not spent any money on tools in

years. Maybe the odd hand tool, but apart from that, no.

**HS** Are you down there often at Leeds Hackspace?

**Al** Yeah, because there are a few things that I don't have. So I don't have a table saw for example, so if I'm doing any big work, I need that. I didn't have a drill-press until recently, so it's handy for that. But it's all the weird, obscure tools that they've got, like old imperial taps for cutting threads, and things that have been collected over the years.

Tools-wise, it was just a case of picking stuff up as I go along. I had Richard Morley (@brainfizzUK) at the weekend, and he was teaching me how to use a router, and he just gave me some clamps, because he knew that I didn't have any.

I come out here for a bit of sanity after the day's work and the stress. I come out here to regress, to have fun, and be a kid again

But he also, more importantly, knows that they're useful, so it's not just that you're giving people tools, you know that they'll use them.

Someone told me, "You really need an angle grinder" and gave me one. And then, the second I start using one, I realised that yes, I did need an angle grinder. I can carve grips for guns because I've got an angle grinder now. I had absolutely no idea how I would have done that before. Do I just stand there with a file and go at it for several hours? I did that in seconds. I hurt myself, but it was fun and I learned a lot.

I guess we all try to help each other out, which is just beautiful. More and more I understand why this community is so good, everybody loves it, everybody's involved and is happy to give advice and to help each other out.

I guess it's the same down at Leeds Hackspace. I like going down there because they've got tools, but I like it more that I can ask someone about a problem I'm having with the Raspberry Pi or something. Or, if I can't get a motor driver working, someone'll point to a guy in the corner who's a motor driver expert – go and ask him. A lot of people down there aren't even making anything, they're just there because they want to help, and they want to give advice and share skills.

**HS** There's a lot of sharing going on in the maker world. In online communities, there's a lot of gate-keeping. Gaming for example, seems to be incredibly toxic. And making is the complete opposite.

**Al** It's not just sharing in terms of tools and skills. People also get a lot of emotional support from making. A lot of us are not necessarily the most outgoing people, but all of a sudden ... a lot of people talk about men's health issues, you know. Like you say, toxicity and bullying – especially on YouTube. There might be some horrific comments and people get upset by that – but then when you come and talk and open up to, essentially, strangers... Until Makers Central, I'd not met my fellow podcasters in the flesh, but we all kind of had this trust in opening up to people and sharing everything.

**HS** What you said about men's health, that's the whole point of the Men's Shed movement. What you make is absolutely secondary to who you make it with.

**Al** I come out here for a bit of sanity after the day's work and the stress. I come out here to regress, to have fun, and be a kid again. I've got 1000 subscribers on my YouTube channel, which is unbelievable; I didn't ever think that would happen, I was only doing this for a laugh. For that video, it happened to coincide with Movember, so I was sporting a ridiculous inverse handlebar moustache. ↵



Above □  
When the zombie apocalypse comes, you'll wish you too had a chainsaw on a stick

I was able to just talk to people. I didn't know who was watching, but I was able to talk about a cause that I believe in every year, shave my face for a joke so people take the piss out of me and raise a few quid, but all of a sudden there's 1000 people watching me. What started out as me having a laugh in a shed turned into me being able to have a conversation about things that I'd never done before.

A lot of people got in touch with me and talked about their problems and challenges and stuff. Around the world ... people opening up about issues they'd never talked about before. It's unbelievable. People who have a platform almost have a obligation to use it in the right way. Without being preachy, I mean, yes, make people laugh, but also do a little bit of good as well. You might influence just one person to make a different decision to the one they were going to make, because you've said the right thing. That's the great side this this. But also, I get to make Wolverine claws.

**HS As well as the Fools With Tools podcast, do you do a lot of collaborating with other makers?**

**AI** I try to. At the moment, it's a question of time. I've got something in the pipeline, building a bike. Someone I know has a logistics company and he wants to do a promotional thing in town where he can take paperwork around town. He wants an electric trike with a big archive box on it. We were discussing it, and it could be this cool-box-style ice cream or hot dog box, like they have outside baseball games, with the big wheels. And then we thought, because he has a logistics company, it could be a miniature trailer, like a tiny HGV wagon that looked a bit like Optimus Prime. Because he knows me, he can say, "I want this, but with your nonsense madness on top of it. What's the AI style that you can put on this?", and then work out the electronics and the mechanisms that it'll need, the power training and

stuff. That's a really big build, and it's going to be in the works for a while.

I want to do more collaborations, it's just a matter of time. There are a few makers locally who I'd like to work with. There's a chap called Owen in Leeds, who makes knives. There's a guy called Tim in Huddersfield; he's an electrician and he does a lot of woodwork as well.

**HS Metal, wood, computing – you seem to do bits of everything.**

**AI** That's what appeals to me, that's what I like doing. I know absolutely nothing about one particular thing, but I know enough about lots of things. I know enough to get by. I'd never done anything with compressed air or pneumatics, and so building this cannon I had loads of questions. The instructions online

**I studied electronic engineering at university, and that was what got me into fiddling around with stuff, taking things to bits, and seeing how they work**

are all for American standard parts and in Imperial measurements. British gas threads go the wrong way round, so I've been completely winging it, picking up things from here and there, and it works.

Bits of everything is what inspires me. I studied electronic engineering at university, and that was what got me into fiddling around with stuff, taking things to bits and seeing how they work. So I can make an electronic device quite happily, but then I need something for it to live in, and wood's just the easiest thing to work with. But then when I found out that you could cut metal! I'm working on a full suit of armour made out of aluminium.

This is something I'd never done before, and when I found out that it's just as easy to work with metal, I cut these parts out

with a hacksaw. It's not the correct way to do it – you should use a big shear and use the correct equipment, you could laser-cut it or use a plasma gun. But if you put a woodworking blade in a jigsaw, you can cut aluminium, it's fine.

**HS Where did you get the bits from?**

**AI** A lot of it is scrap. I've got a friend who installs solar panels, so he's got all sorts of scrap-metal kicking about. There's a galvanised steel pipe in there [Al gestures to a pile of stuff in the corner of the shed]. That was a chimney flue, but it's going to be the silencer of the rifle.

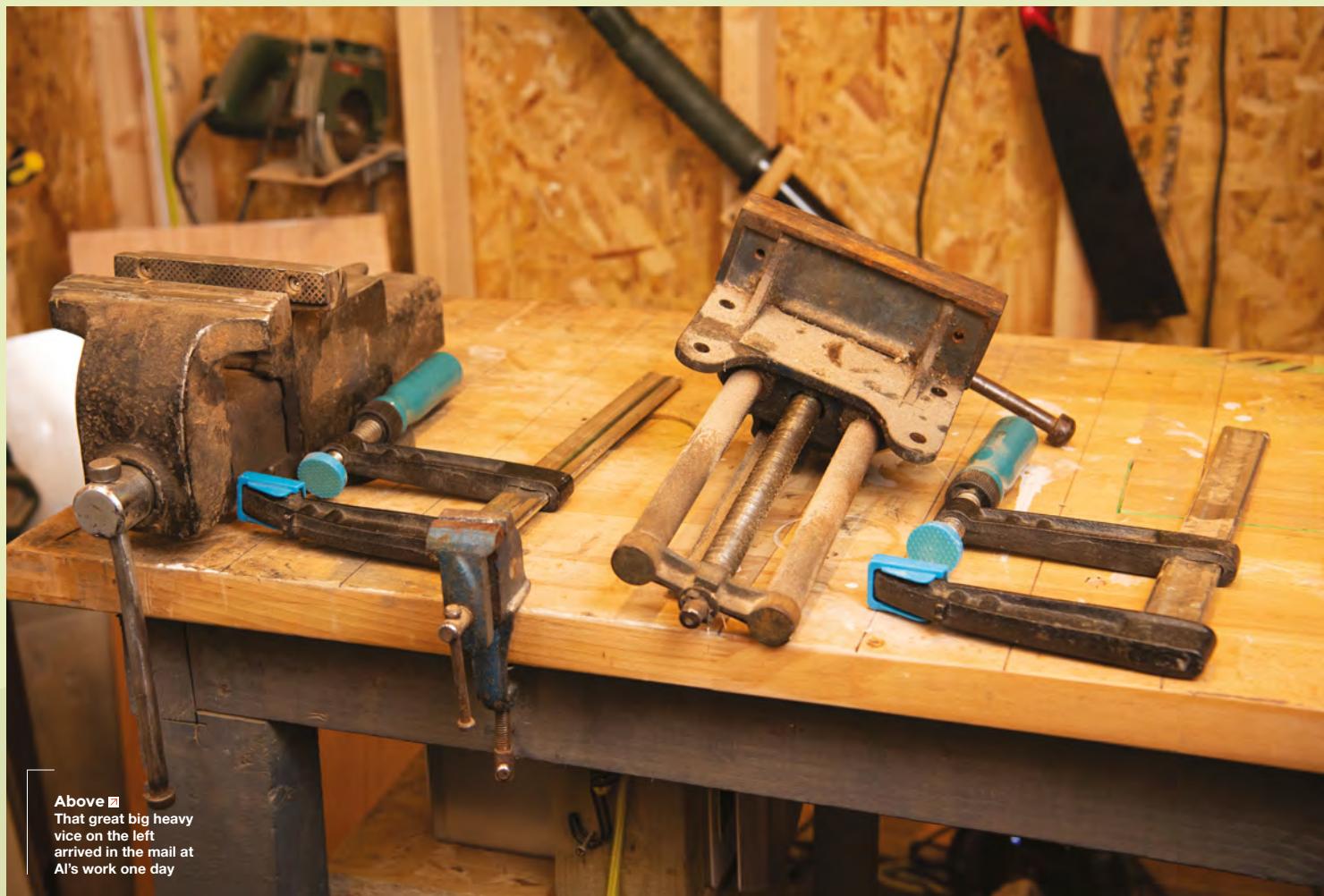
I also try not to buy anything. What I'm doing is comedy, it's hacked together; I'm not doing fine woodworking. None of this is for sale, you know, the only person who has to worry about build quality is me.

If it works, it works. With the beer fridge, I had to learn how to make it work, but the principle, the voice activation and the electronics of it, that's what I was trying to learn. I want more voice control in the shed, because it's only me on my own. I want a Jarvis, like in *Iron Man*.

**HS Ah yes, the beer fridge. In one of your early videos, you build a voice-activated beer fridge into your workbench. Is that still working?**

**AI** Yes, the voice control works. You know when you get buzzed into the outside door of a building? You hear a click, then you have to pull it before you push it, because the strength of the solenoid cannot hold the door. It's the same with the beer fridge. It works, but you've still got to unlock it. It electrically unlocks it, but doesn't physically unlock it.

There are a couple of bungee cords as the spring that makes the beer pop up, coupled with an electronic door-lock. That's how, in my head, it works. How do you unlock something electrically? With a door-lock. It runs off 12 volts, and you plug in into a Pi. I know enough circuitry →



**Above** That great big heavy vice on the left arrived in the mail at AI's work one day



**Above** This miniature effigy was created by fellow maker @makeit\_soph. It's even holding a little can of beer

that I can convert 12 volts into 3 volts, so I can translate the inputs and outputs from the Pi into something that will power that. I cut a hole in the top of a fridge, so when I give the command, beer pops up.

The voice activation thing for me was kind of a game-changer. It got put to the wayside a little bit, because of Echo and Google Home. I think they became so cheap and so available that people didn't need to push using their own versions any more. So I got the Google API – that's what I used with the hack bench – and they put limitations on, like you couldn't use the voice activation to wake it up. On a Google device you can say, "Okay Google"; on the API you can't do that.

I got around that by recreating a button press with a voice command. I bought it to recognise my voice as a button being pressed. You can replace pin 7 on the Pi as an input with a line of code, for example.

Once you've got around that, you can use it as a Google Home, telling it to play this or that song on Spotify, or turn down the Philips lights, or whatever.

I much prefer the analogue world. If I could voice-control the woodchopper, that would be way more exciting. The plug died on my lawnmower, so I could plug it in, but I couldn't turn it on or off. Suddenly it was lethal because I couldn't turn the lawnmower off. It could either be on and running, or unplugged. So instead, I hooked it up with voice activation and announced to it "turn on the lawnmower!" That wasn't me trying to be clever. It was me solving a problem. Otherwise, I had this lethal thing spinning constantly. But voice activation gives you so many opportunities. If you can work out how to do one thing, you can do a million things. I can code, I understand it a little bit. But I love the things that you can do with it.

**HS Is there any reason you chose a Pi rather than one of the many, many other single-board computers on the market?**

**A1** I am not old enough to have been part of the BBC Micro era in the 1980s. I know it's had a resurgence recently with the little mini one you can get. The micro:bit. I was also epileptic as a kid, so I wasn't allowed to get involved with computers. So, as a 20-year-old studying electronic engineering at university, I went for it:

computers, computers, computers. When the Pi came out, I could have the power of it in my hand, it cost me £20, and I could do what I want. Control the inputs, make a retro console in my living room...

I've got two Pis now, a 2B and a 3, I think, and both of them have been a million things already. I've used it as a console, I've used it as a network-attached storage system with a little hard drive,

**I've got two Pis now, a 2B and a 3, I think, and both of them have been a million things already**

[for] voice control activation, [and] as a media server, and I love it for that. You can get this one little cheap thing straight out the box and just start tinkering with it. I love being able to modify things.

There's so many rules when you're a kid; when you become an adult and you realise that you can break the rules... If I'd had a Raspberry Pi when I was a kid, I'd be on Mars now.

Because having that understanding and that power, being able to write your own stories in Scratch and Python, they're just unbelievable. Incredibly simple to understand, but there are real-world consequences, you can attach things up to it. Even just turning on an LED: all of a sudden it's like, "if I can turn on an LED, I can have beer pop out of my bench". It's the same thing. That for me is the wonderful thing about it. I just wish I had more time to get into the guts and the brains of it, and really understand it. □





Secure your builds with this crafty little fastener



**Mayank Sharma**

 @geekybodhi

Mayank is a Padawan maker with an irrational fear of drills. He likes to replicate electronic builds, and gets a kick out of hacking everyday objects creatively.

**F**or something that looks so basic, the clothes peg is a fairly recent invention. This all-important weapon in our battle with the wind made its debut only in the 19th century, which is a shocker, especially when you consider that hand grooming kits were in vogue in ancient Rome.

In its short period of existence, the clothes peg has essentially only had one revolutionary design upgrade. The first versions were a one-piece design, and they were commonly made by hand by the Romani in Europe. It's often claimed that sometime in the early 1800s, a patent for this design was given to someone named Jérémie Opdebec, about whom there is little to no information. These early one-piece clothes-pins were usually made of wood. Still in production these days, they are known as 'dolly pegs' and, in addition to wood, are also made from plastic.

Between 1852 and 1887, the US patent office issued almost 150 patents for clothes pegs. The more modern-styled clothes-pin came about in 1853. It was invented by David Smith, a serial American inventor,

and featured two separate pieces of wood and a spring. This design was tweaked in 1887 by Solon E Moore, who added the characteristic coiled fulcrum to join the two grooved pieces of wood at the centre of the clothes peg. Made from a single wire, the pegs were now stronger and cheaper to manufacture. However, the pegs had a limited lifetime, as they were prone to decay and rust. This changed with the invention of stainless steel. These days, clothes pegs come in a variety of shapes, sizes, and colours, but they all usually feature a spring between two wedge-shaped pieces of plastic, although you can still find some made from wood as well.

While made to secure wet clothes on a clothesline, the clothes peg has always been used for other purposes. Hollywood actress Diane Keaton has proudly admitted to using one to reshape her nose, and proponents of ear reflexology suggest using a clothes peg instead of finger pressure to one of the key pressure points. They are also famously used on movie sets to handle the hot diffusers on film lights. So, it really isn't a surprise that intrepid makers have clamped on to them.

# IPAD PIANO



**W**hile writing code for musical instrument apps, Adam Kumpf was very conscious of the incomplete interaction between the users and the touchscreen: "I remember being constantly frustrated by the direction things were going with mobile tech design.

Next-generation tablets and smartphones seemed like a bland sea of flat, tactile-less interactions. I was spending my days writing code for musical instrument apps, and constantly felt the tension between all the capabilities of the device/software, and how flat everything felt (literally), because it was just fingers on a screen."

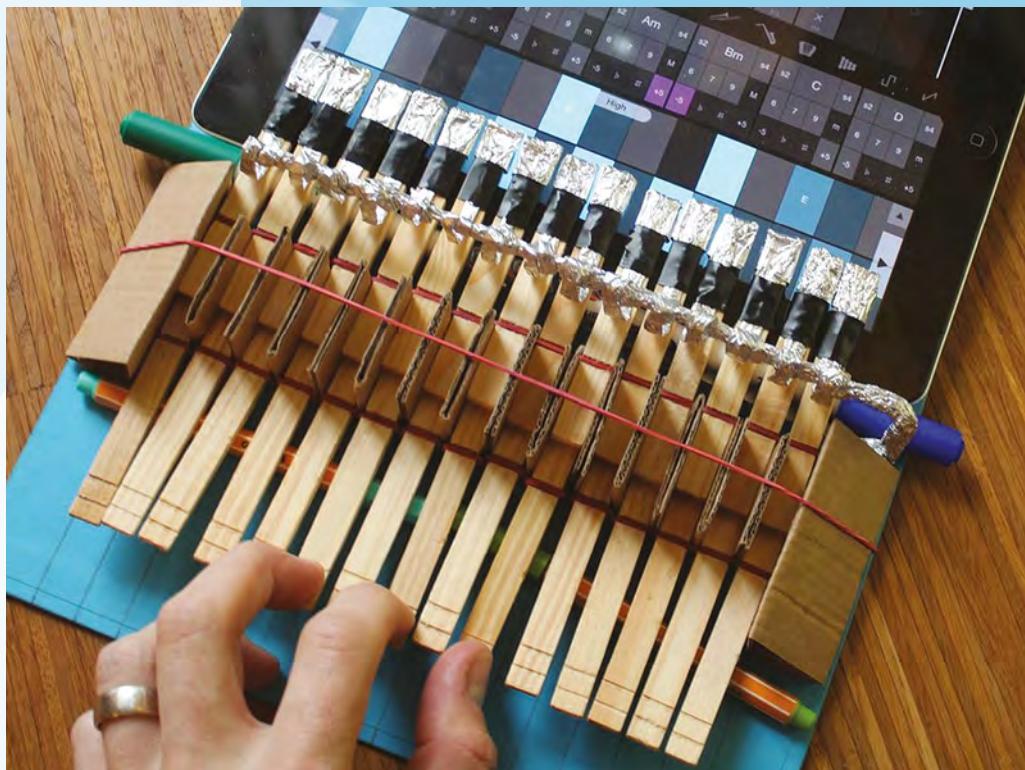
So Adam, who has a background in computer science and tangible interfaces from MIT, decided to make something that "resembled the interaction of a piano without changing the multitouch app on the tablet." He headed to the store and picked up a couple of inexpensive bits and pieces, and had a fully functioning keyboard by the next day. He used some aluminium foil and clothes pegs to trick the iPad into thinking it was his fingers playing the keyboard on the touchscreen. His Instructable has detailed explanations, and each step is illustrated to help you hack the clothes peg keyboard in a jiffy. □

**Project Maker**  
**ADAM KUMPF**

**Project Link**  
[hsmag.cc/KIEQRd](http://hsmag.cc/KIEQRd)

**"I REMEMBER BEING CONSTANTLY FRUSTRATED BY THE DIRECTION THINGS WERE GOING WITH MOBILE TECH DESIGN"**

**Below** Adam has a couple of capacitive touchscreen hacks under his belt, and you can check out his current ones at Makefast Workshop



# PEG HANDS

**I**t was when he was desoldering one of the tiny resistors on the ESP-12 chip that Suwardi Thio felt he could use an extra pair of hands to handle all the equipment. So, he decided to adapt his DIY Tool Organiser project, along with his ingenious multifunction twister wires, to create his own pair of helping hands. The wires are attached to a piece of board that Suwardi suggests should be at least 2 cm thick to better support the artificial limbs. You can drill holes in any pattern on the board, but he

spaced the holes 5 cm apart from each other. To create the twister wires, he runs different lengths of the standard 2 mm electrical wire through small PVC hoses. One end of the wire is connected to the board, while the other is attached to the clothes peg via its spring hole. The exact process of connecting the wire to the board and the peg is nicely explained and illustrated in his Instructable. He uses wooden clothes pegs instead of alligator clips, since they are made of softwood and won't scratch the delicate electronics. □

**Project Maker**  
**SUWARDI THIO**

**Project Link**  
[hsmag.cc/YUbwTF](http://hsmag.cc/YUbwTF)



**Left** ◇  
Suwardi's pair of peg hands are very sturdy and, besides handling electronics, he uses them for smartphone photography

# CLOTHES PEG LAMP SHADE

**J**im is an old-school maker, and refuses to use modern-day conveniences like laser cutters, laser printing, CNC routers, and such: "My view is that the 'feeling' or individuality is lost from a piece of art or whatever you call it, using standardised machines." This is why in order to create the wire frame for his clothes peg lampshade, Jim shaped a galvanised steel wire into seven concentric rings by hand. To close the loop, he heated the fastening point where the wires meet and applied the solder. The seven concentric rings were connected via four vertical strips of wire using the same soldering mechanism. With the wire frame in place, he simply started clipping the clothes pegs to the ring at the bottom and worked his way up. Jim suggests placing the pegs carefully to ensure the ones in each subsequent row overlap the ones underneath it. □



Project Maker  
**JIM NEIL BERG**

Project Link  
[hsmag.cc/sAvIPN](http://hsmag.cc/sAvIPN)

**Left ↳**  
Make sure the rings aren't too far from each other, or else the pegs will loosely dangle on the frame

# SIMPLE DOOR ALARM

**Z**hyar is a 16-year-old maker from the Kurdistan region of Iraq, and hosts the Kurdish Inventor YouTube channel. One of his projects involves creating a simple door alarm using a clothes peg with copper strips attached to both its inner lips. The copper strips have small pieces of wires attached to them. Both are connected to a 9V battery, with one running via a  $1\text{ k}\Omega$  resistor, an LED, and a buzzer. The whole contraption is mounted on a Styrofoam board and hot-glued to the side of a door. He wraps a piece of wire on the door handle, and connects the other end to a piece of card that's placed between the two

copper strips on the clothes peg. When the door handle is turned, the piece of card is dislodged, and current flows between the two lips of the clothes peg, arming the buzzer and activating the LED. □



Project Maker  
**STUDIO STYLENRICH**

Project Link  
[hsmag.cc/Oxweyh](http://hsmag.cc/Oxweyh)

**Left ↳**  
The YouTube channel ([hsmag.cc/arvnOO](http://hsmag.cc/arvnOO)) has loads of electronics-related and other DIY projects

# WIN!

1 of 5

## Hackster Glowboard Skateboards

How will you hack yours?

[hsmag.cc/win](http://hsmag.cc/win)

Enter by 2 November  
for your chance to win!



### Terms & Conditions

Competition opens on 19 September 2018 and closes on 2 November 2018. Prize is offered to participants worldwide aged 13 or over, except employees of the Raspberry Pi Foundation, the prize supplier, their families or friends. Winners will be notified by email no more than 30 days after the competition closes. By entering the competition, the winner consents to any publicity generated from the competition, in print and online. We don't like spam: participants' details will remain strictly confidential and won't be shared with third parties. Prizes are non-negotiable and no cash alternative will be offered. Winners will be contacted by email to arrange delivery. Any winners who have not responded 60 days after the initial email is sent will have their prize revoked. This promotion is in no way sponsored, endorsed or administered by, or associated with, Twitter or Facebook.



# FORGE

## HACK | MAKE | BUILD | CREATE

Improve your skills, learn something new, or just have fun tinkering – we hope you enjoy these hand-picked projects

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A touch-sensitive edible treat to wow your party guests

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### POCKET HOLE

Make wooden joints the easy way

# Arduino programming: build a games console (part 2/2)

Tackle all the main gameplay elements, from terrain generation to collision detection, and combine them into an addictive, easily modifiable game

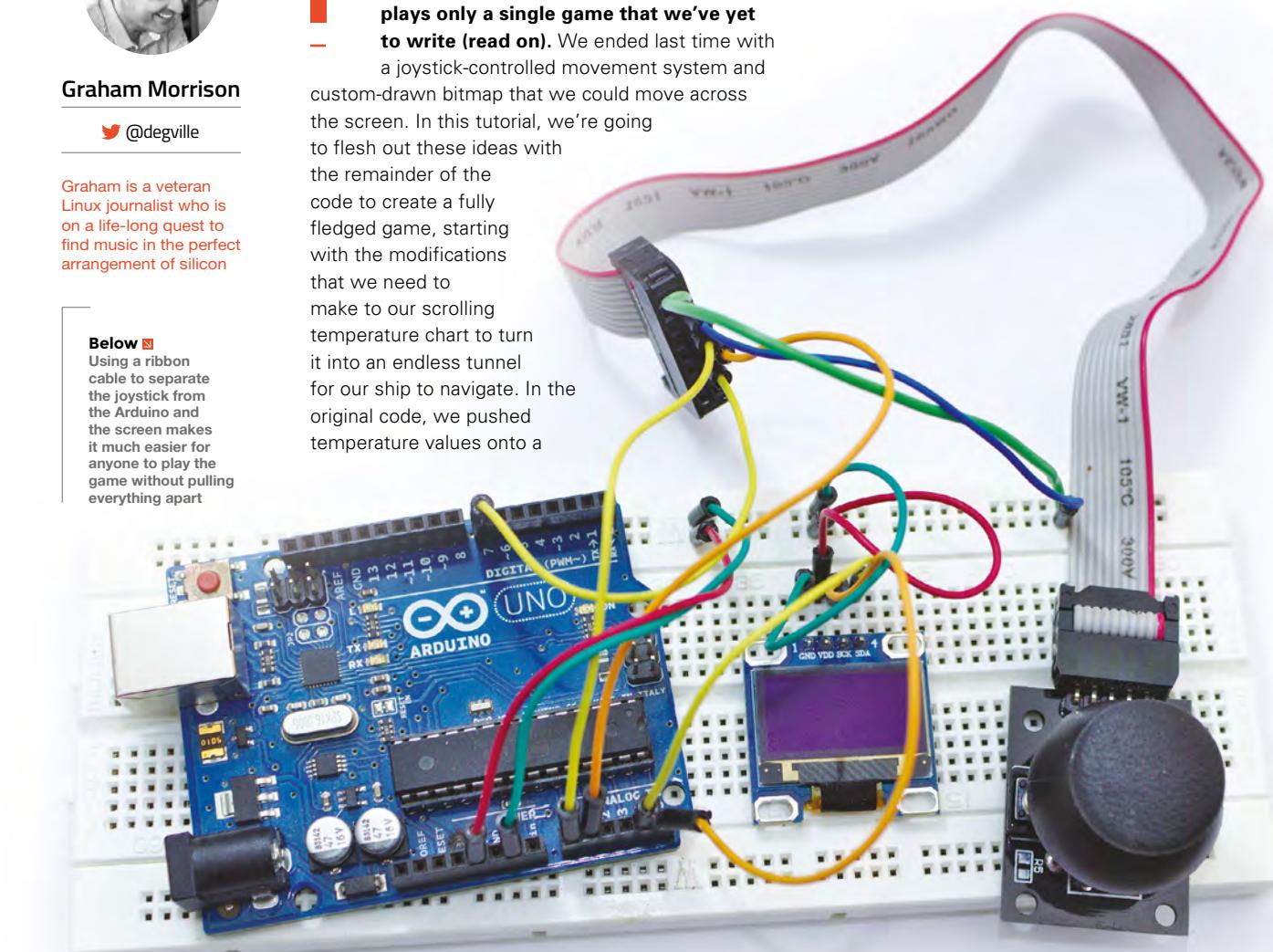


Graham Morrison

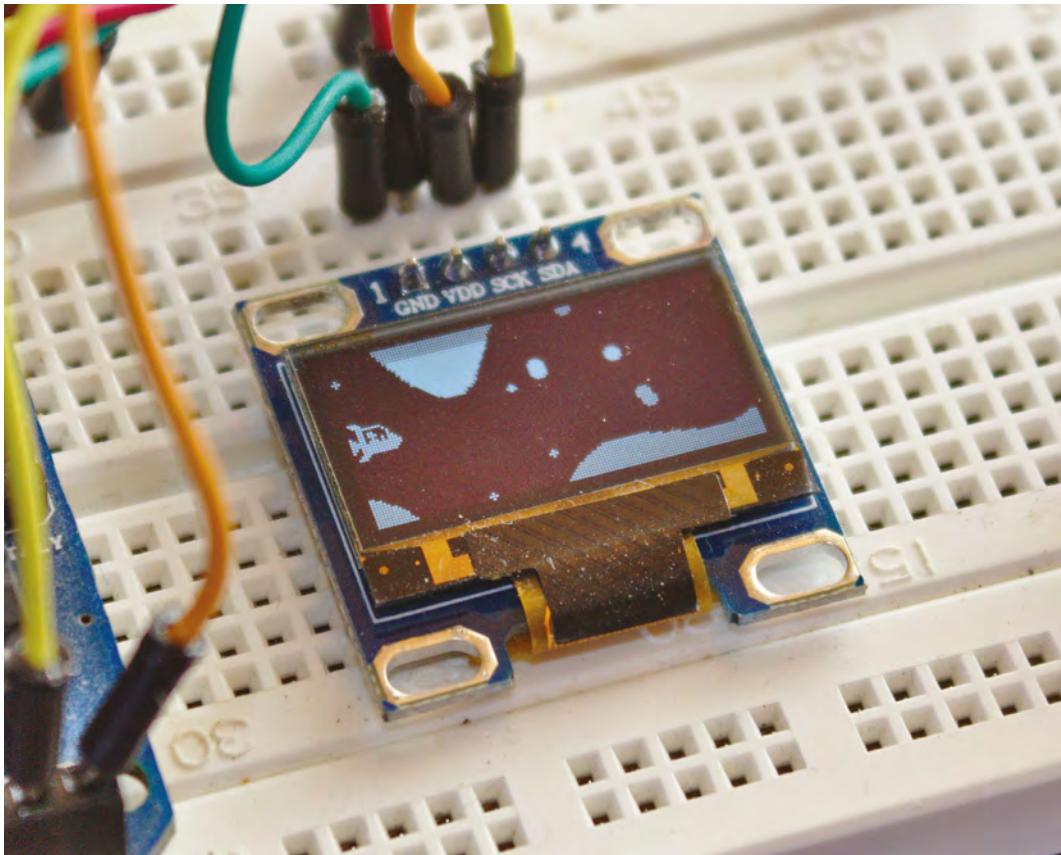
@degville

Graham is a veteran Linux journalist who is on a life-long quest to find music in the perfect arrangement of silicon

**Below** Using a ribbon cable to separate the joystick from the Arduino and the screen makes it much easier for anyone to play the game without pulling everything apart



In the previous tutorial, we started on our adventure of turning a humble Arduino Uno into a games console, albeit one that plays only a single game that we've yet to write ([read on](#)). We ended last time with a joystick-controlled movement system and custom-drawn bitmap that we could move across the screen. In this tutorial, we're going to flesh out these ideas with the remainder of the code to create a fully fledged game, starting with the modifications that we need to make to our scrolling temperature chart to turn it into an endless tunnel for our ship to navigate. In the original code, we pushed temperature values onto a



**Left ↗**  
The aim of the game is to steer your ship for as long as you can through a tunnel whose dimensions are ever decreasing

stack and read back those values into each column of the screen. These values were held in a stack and as we added a new value, the oldest one was removed. This created a sliding window of the last 128 values. The screen is also 128 columns wide, and drawing these values (one position per column) has the effect of creating a scrolling display of values that move from the right to the left.

We're going to subvert this effect to turn those values into a cross-section of a cave for our spaceship to fly through, and the first step is to replace the temperature readings with something we can generate indefinitely as a kind of landscape generator. There are many creative ways of doing this, but we've settled on using a couple of `sin()` (sine wave) generated values that change according to two counters. The first `sin()` value will be used to generate the height, while the second counter is used to adjust the angle jump for the next value. The result is a modulated sine waveform that looks almost natural, while providing enough unpredictable variation to be a challenge. The following code does the job, and it needs to replace the old stack code in the `loop()` function:

```
void loop() {
    if (playstate) {
```

**“ Adding values to our stack is only half of the solution. The other half is how we render those values to the screen”**

```
if (counter > 180)
    counter = -180;
if (second_counter > 120)
    second_counter = -90;
land_stack.push((sin(counter * 3.1 / 180) +
1.1) * (4 * difficulty));
counter = counter + sin((second_counter++ *
3.1 / 180) + 1.1) * difficulty;
```

One addition in the above we've not yet mentioned is the `difficulty` variable. We're going to scatter these throughout our code to act as multipliers that make calculations more extreme. The idea is that we can increase the difficulty in the game by increasing the value held in the `difficulty` variable.

Adding values to our stack is only half of the solution. The other half is how we render those values to the screen, and because we want to turn those values into a scrolling tunnel rather than a scrolling histogram, we need to →

### QUICK TIP

If you want to save yourself the bother of putting all the code together, the code for the entire project can be found here: [git.io/fNXzh](http://git.io/fNXzh)

## SCHOOL OF MAKING

### ADD A STARFIELD

Even though it's not necessary for a game where a spacecraft flies through an imaginary cave, there's one simple and old visual effect that adds depth and movement. And that's the starfield. A starfield shows 'stars' of pixels scrolling alongside the player, with some moving faster, and some moving slower. This creates an impression of parallax, where the slower-moving stars seem further away, especially if you make those stars smaller. You still find a starfield used in many games, and even realistic space simulators, like Elite Dangerous, find an excuse to drop moving pixels into what would otherwise be empty space. A fully three-dimensional starfield is slightly more complex, as would be a properly calculated two-dimensional starfield, but you can create a realistic approximation of a starfield using an array of a simple structure that holds the x, y, and speed values for each star:

```
struct stars {
    int x, y, speed, size; };
stars starfield[MAXSTARS];
```

We've defined `const int MAXSTARS = 10;` as a global value for the amount of stars to draw, but you can actually increase this to whichever value suits you best, depending on your Arduino memory. We've also added a `size` variable to give ourselves more rendering options. To draw the starfield, we'll create a separate function:

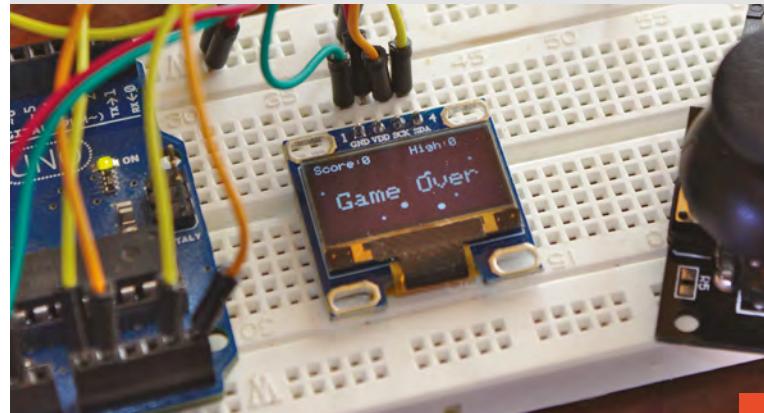
```
void displayStars() {
    for (int i = 0; i < MAXSTARS;
    i++) {
```

```
        display.
        fillCircle((starfield[i].x / 10),
        starfield[i].y, starfield[i].
        size, WHITE);
        starfield[i].x =
        (starfield[i].x - starfield[i].
        speed);
```

You can see how this is a simple hack to place the stars, drawn as circles with a radius that equals the star size, at their x and y co-ordinates on the screen. We then subtract the speed value from the x position to move the star along for next time. One slightly unintuitive part is that we're dividing the x value by 10, and that's because we intend to initialise this value with a random number that could be ten times the width of the screen. By doing this, we allow stars to move at a rate slower than one x value per iteration, so that the further stars move slower.

When the star hits the left border, we regenerate it by assigning random values to everything except x, as we now want it to appear on the right screen border. This is where we give it the `display.width() * 10` value just mentioned:

```
if (starfield[i].x < 0) {
    starfield[i].x = (display.
    width() * 10);
    starfield[i].y = random(0,
    display.height());
    starfield[i].speed =
    random(1, 50);
    starfield[i].size =
    random(1, difficulty - 2);
}}
```



modify the `displayChart()` function, which we've renamed `displayTunnel()`.

### TUNNEL VISION

The principle behind drawing the tunnel is simple. We take the height values that we've pushed onto the stack and use them as both the floor height from the bottom of the screen and for the roof height from the top with a value in the middle to define the level of separation between the two. This creates a tunnel effect that will go up and down with the roof and floor moving in parallel. On its own, this wouldn't be very interesting, so we're going to add two modifiers. The first will move the entire tunnel

**We're also adding the 'difficulty' variable here to make things harder or easier depending on its size, and we assign all of this to a single integer called 'height'**

up and down, forcing the player to also move up and down, while the second will make the tunnel smaller and progressively harder to navigate.

To tackle the first, we're going to use another `sin()` to modify the height level we've pushed onto the stack, unless that value is zero. We'll link this to the global counter that's already counting through the radians when generating the original height to save creating another counter. We're also adding the `difficulty` variable here to make things harder or easier depending on its size, and we assign all of this to a single integer called `height`:

```
void displayTunnel() {
    int height;
    for (int x = 0; x < MAXSTACK; x++) {
        if (land_stack.peek(x) != 0) {
            height = display.height() - ((land_
            stack.peek(x) + sin(counter * 3.1 / 180) *
            difficulty));
```

We can now draw both the roof and floor by using the height to either draw down from the top of the screen or up from the bottom of the screen. We're using a global integer called `tunnel_size` to set the number of pixels high we want the tunnel to be, and we subtract half of the value it will hold from roof and floor heights to carve out a space for our ship:

```
display.drawLine(x, height - (tunnel_size / 2), x,
-1, WHITE);
display.drawLine(x, display.height(), x, height +
(tunnel_size / 2) , WHITE);
}}
```

That's all there is to the tunnel generation code, although we'll be revisiting the function to add a simple collision detection, as we'll now see.

## COLLISION DETECTION

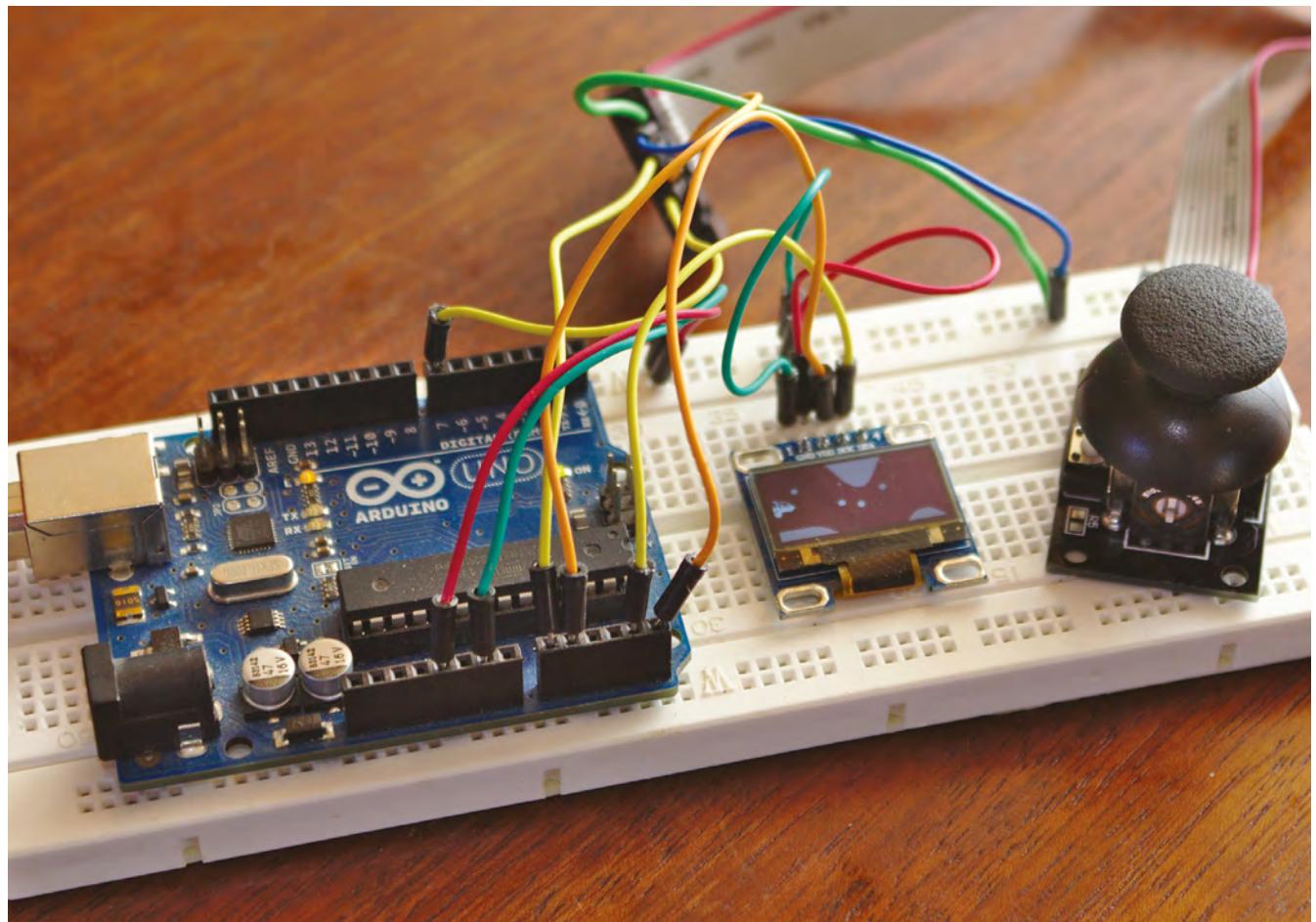
There are now just two functions left to write or update, and these updates are both going to manage keeping a score for the player. We've decided to go with a simple timer that will reward the player for surviving, and that needs a way of ending the game, which we're making an event when the ship crashes into the cave wall. There are many ways to do this. For the ultimate in accuracy, for example, you'd save the state of what the ship could collide with into an array and then check those locations against the pixels

you know are part of the ship bitmap. This solution is complex and will steal considerable resources, and just like those original games designers of the 1980s, we need to cut corners. Our solution is to use a global true/false (Boolean) variable called **playstate** to store whether the game is still in progress. If the game is still in progress, we run through the functions that update the ship location and the tunnel, then increase a counter that holds the score. If the game isn't in progress, then show a 'Game Over' message.

We're going to insert the collision detection into the **displayTunnel()** function we've just updated. After the two **drawLine** lines, add the following: →

**Below** Once you've got everything working, you might want to consider a more permanent setup

**"** We've decided to go with a simple timer that will reward the player for surviving, **and that needs a way of ending the game**



## SCHOOL OF MAKING

```
if (x == shipx) {
    if ( (shipy < (height - (tunnel_size / 2)) )
    || ((shipy + 12) > (height + (tunnel_size / 2)) )
    ) {
        playstate = false;    }}
```

All the above code is doing is checking to see whether the ship is in the vicinity of the current 'x' position where the tunnel is being drawn. If this is true, see whether its edges are likely to hit the roof and floor heights we've just calculated. If we detect a collision, we set the **playstate** to false, triggering the end of the game section in the **loop()** function. And that's where we turn our attention to next:

### 10 ESSENTIAL IMPROVEMENTS

The great thing about games like this, and our simple implementation, is that it offers all kinds of opportunities to make it better, and those improvements are perfect challenges if you're learning how to code. With that in mind, here's our hit list of new things we'd love to see added to our game to make it even better:

1. Increase the score multiplier the further to the right of the screen your ship is, adding to the risk reward and difficulty.
2. Add the score and high score to the play window so you can see how you're doing.
3. Make the collision detection more accurate.
4. Use the **difficulty** variable to increase the difficulty the more time you spend playing, and even add levels and level markers.
5. Find a way to reduce the tunnel size off screen, rather than showing the transition while you're playing.
6. Give the player more than one life and show these on the screen.
7. Animate the ship by using more than one bitmap, and add rocket pixels that appear only when you're moving to the right.
8. Use collision detection for the stars, and start off with fewer stars, making the player dodge these as they fly through the tunnel.
9. Add gravity so that the ship starts falling to the floor when you're not directly thrusting up.
10. Add aliens and use the switch to fire a laser to destroy them.

#### QUICK TIP

The joystick scaling is currently linear, but you can make the controls more interesting by playing with the input and output values so there's finer control at the joystick's extremes, for example.

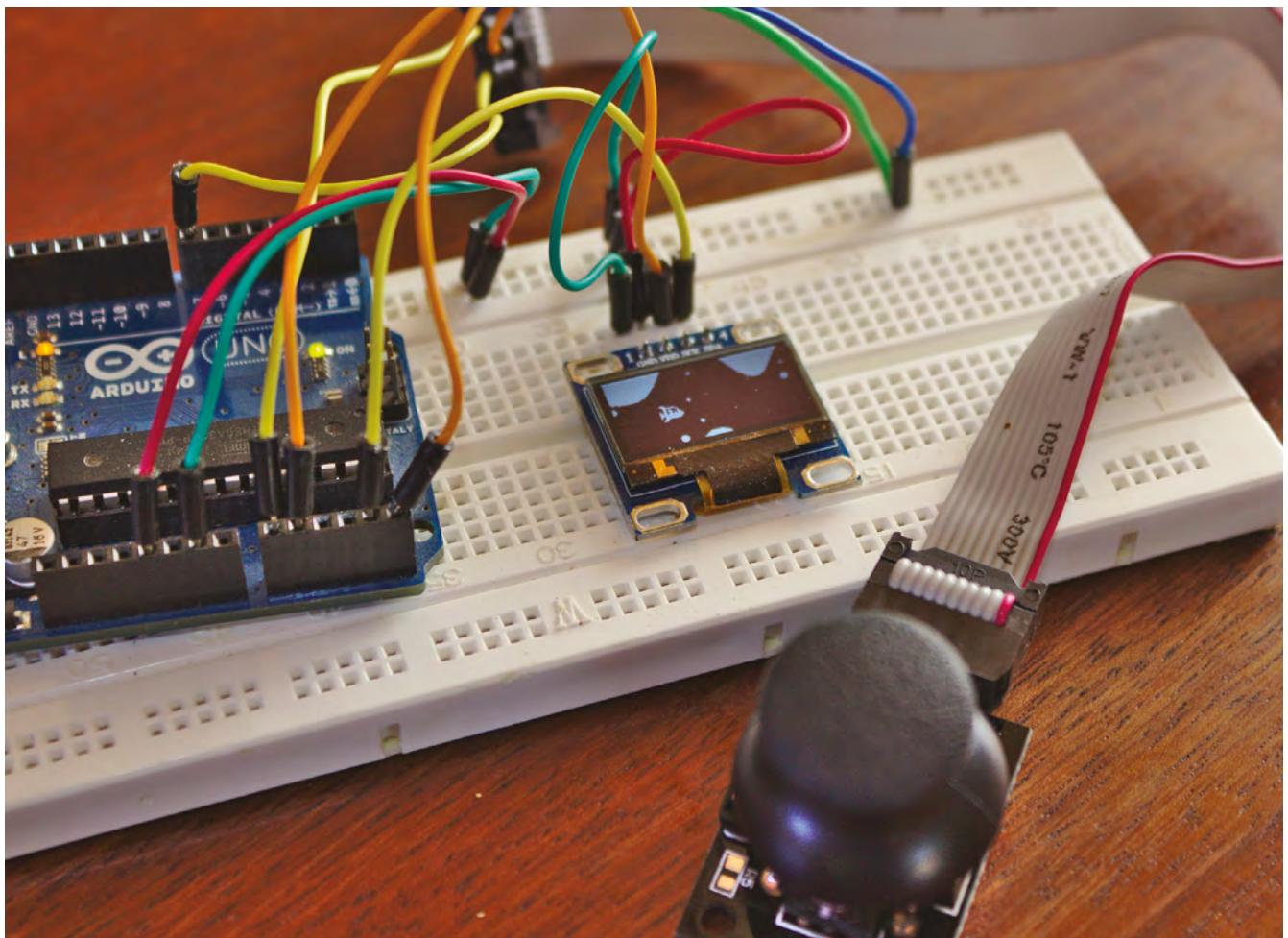
```
void loop() {
    if (playstate) {
        // counter code
        updateShip();
        displayTunnel();
        displayShip(shipx, shipy);
        // displayStars(); uncomment for starfield
        if (score_counter++ == 100) {
            tunnel_size--;
            score_counter = 0;
            current_score++;
        } } else {
        displayStars();
        displayScore();
        switchstate = digitalRead(SWITCH_PIN);
        if (switchstate == LOW) {
            initGame();
            playstate = true;
        } }
        display.display();
        delay(1);
        display.fillScreen(BLACK); }
```

With the exception of the radian counter and stack code covered earlier, this is our new **loop()** function in its entirety. While the **playstate** is true, it runs through drawing the ship, the tunnel, and the stars (see 'Add a starfield' box on page 70), increasing the score. After every 100 iterations,

**“** **If the playstate changes to false, we display the score (and the starfield!) and wait for the player to press the joystick switch to start the game** **”**

we reduce the size of the tunnel, making the game harder. If the **playstate** changes to false, we display the score (and starfield!) and wait for the player to press the joystick switch to begin the game. This is also the default state when you start the game. We then update the display and blank it after a delay, ready for the next frame. There are two new functions referenced in this code we need to write: **displayScore()** and **initGame()**. The first simply checks if you've got a new high score, and prints both values to the screen:

```
void displayScore() {
```



```

if (current_score > high_score)
    high_score = current_score;
display.setTextSize(1);
display.setTextColor(WHITE, BLACK);
display.setCursor(0, 0);
display.println("Score:" + String(current_
score) + "    High:" + String(high_score));
display.setCursor(10, 28);
display.setTextSize(2);
display.println("Game Over");
}

```

The second initialises all the values we use in the game for the player to start afresh:

```

void initGame() {
    counter = 45;
    second_counter = 45;
    difficulty = 5;
    shipspeed = 10;
    shipx = 10;
    shipy = 10;
    switchstate = 0;
    tunnel_size = 80;
    current_score = 0;
}

```

```

for (int i = 0; i < MAXSTARS; i++) {
    starfield[i].x = random(0, (display.width()
* 10));
    starfield[i].y = random(0, display.height());
    starfield[i].speed = random(1, 50);
    starfield[i].size = random(1, difficulty -
2);
}
for (int x = 0; x < MAXSTACK; x++) {
    land_stack.push(0);
}

```

All that's left to do is declare the global variables we've littered throughout our code, giving them default values as necessary. With this done, you can send the game to your Arduino and start trying to beat my high score of 32:

```

Stack land_stack;
int counter, second_counter;
int difficulty;
int shipspeed, shipx, shipy;
int switchstate;
int tunnel_size;
int current_score, high_score, score_counter;
bool playstate = false;

```

**Above** A simple setup like this could easily be battery-powered and placed into a portable console of some kind

### QUICK TIP

Get other people, especially from your target audience, to try your game (and thanks to Elliott, Kaitlyn, Eden, and Ingrid for testing ours!).

# Electronics 101.3: Inductance

The next step after capacitors is another type of component that is similar but almost the opposite: inductors



Dave Astels

[daveastels.com](http://daveastels.com)

Dave's career started in the 8-bit days, with the Z80 and 6502, and he's been working with computers ever since. Check him out at [daveastels.com](http://daveastels.com) and [learn.adafruit.com](http://learn.adafruit.com)

**I**nductors aren't something you come into direct contact with that much as a maker, but one of their primary effects is the generation of a magnetic field. And that is something we do have many uses for.

In many ways, inductance is very similar to, yet the opposite of, capacitance. As you recall, a capacitor blocks a steady current, but allows high frequencies through. An inductor, on the other hand, lets steady current flow easily, but has higher resistance to alternating current.

Inductors store energy in a magnetic field similar to how capacitors store it in an electric field.

At its most basic, an inductor is a coil of wire. In fact, they are commonly called 'coils'.

For a given length and diameter of coil, its inductance is proportional to the square of the number of turns (i.e. loops of wire). An inductor can simply be the loops of wires, or it can be wound around a core of magnetic material. See **Figure 1** for some examples.

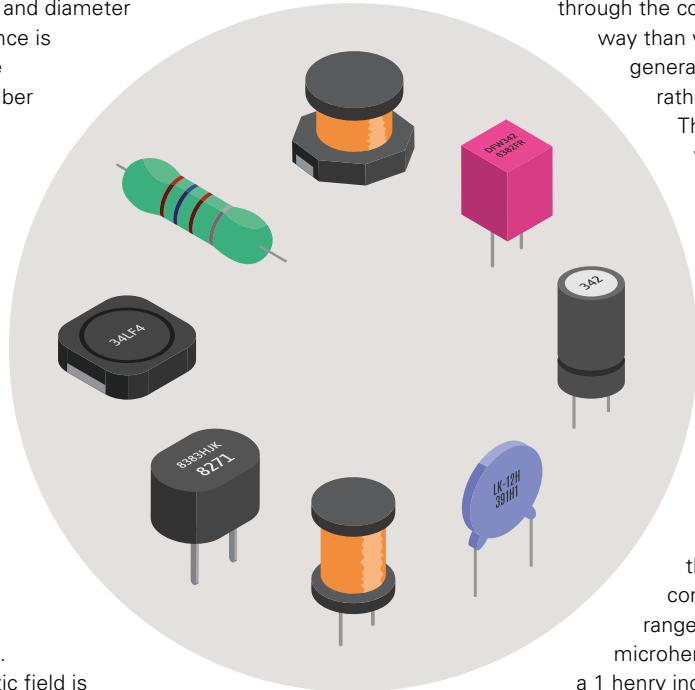
An inductor works by taking advantage of the side effect of electrons flowing through a wire (i.e. current): a magnetic field is

generated around the wire. The orientation of the field depends on the direction the current flows. Another thing is that if you wind the wire into a loop, the fields compound, proportional to the square of the number of winds (i.e. if you double the number of turns, the field gets four times stronger).

The opposite is true as well: a moving magnetic field will induce a current in the coil, resulting in a voltage across it (this is basically how turbine generators work). One side effect of this is that when you remove the voltage from a coil, the magnetic field collapses, which induces a voltage. The polarity is opposite to that of the voltage that generated the field. This makes sense when you consider that the field is moving through the coil in the opposite way than when the field was generated (collapsing rather than expanding).

The resulting voltage/current could damage the connected circuitry, and needs to be shunted harmlessly away with a diode. We'll discuss diodes later in this series.

The unit of inductance is the henry (more commonly in the range of millihenrys or microhenrys): 1 volt across a 1 henry inductor results in a



**Figure 1** ◆  
Inductors are used in a wide variety of parts



**Left** ♦  
This simple wire coil can power an LED from an NFC device

current that increases at a rate of 1 amp per second. With current that large, it's not surprising that much smaller values of inductance are most common.

If you want to delve deeper into inductor history, look into Michael Faraday and James Clerk Maxwell.

You won't typically run into inductors directly; you won't see them in project parts lists. You will find inductors inside other circuits, or in forms that use them for their ability to generate a magnetic field.

Examples of the former case are RF (radio frequency) circuits – radio and other forms of RF communication – and power conversion circuits (see RF Circuits and Power Conversion boxes).

Probably the most common way you'll use inductors as a maker will be for their magnetic effects in the form of electromagnets, solenoids, relays, speakers, and motors. The first three are basically the same thing, with some mechanical differences.

### THE NATURE OF ATTRACTION

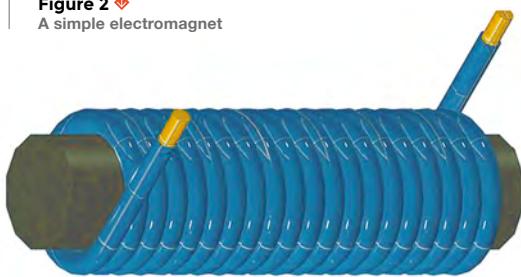
When you put a voltage across an inductor, a magnetic field is generated by the coil of wire. Having the coil wrapped around a core of magnetic material strengthens the field. If you take wire and wrap it around an iron or steel nail, then connect a power source to the coil, you get a relatively strong magnet. Remove power, and it stops being a magnet (although depending on the core, it can retain some residual magnetism). The strength depends on various factors, a primary one being the number of turns to the wire – see **Figure 2**. Due to the currents involved, this can be a somewhat dangerous

**The classic example of an electromagnet at scale** is the crane in a junk-yard that is used to move scrap iron around

experiment since things can heat up a lot – enough to burn if the wire isn't heavy enough, so be careful if you try this at home. That said, there are guides online if you really want to try it. A better approach is to buy an electromagnet (DigiKey, Amazon, and the like have a selection). Most of these will be 12V so you'll need to provide that somehow. You can easily find a moderately small (~30 mm x 25 mm) 12V electromagnet that can lift 10 kg.

The classic example of an electromagnet at scale is the crane in a junk-yard that is used to move scrap iron around. More elaborate and modern examples of electromagnet applications include particle accelerators and magnetic resonance imaging (MRI). →

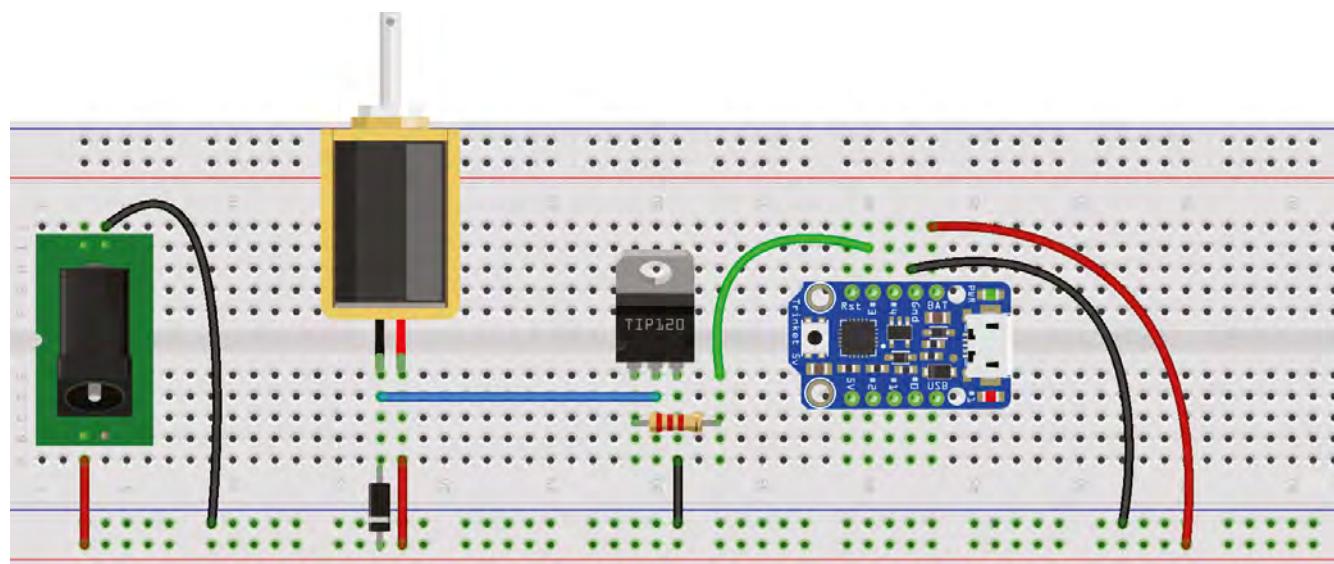
**Figure 2** ♦  
A simple electromagnet



### YOU'LL NEED

- ♦ **Solderless breadboard**
- ♦ **12 V power supply** or battery pack that can be connected to the breadboard
- ♦ **12 V solenoid**
- ♦ **8-32 Ω speaker**
- ♦ **12 V relay**
- ♦ **12 V electromagnet**
- ♦ **TIP120 or ULM2803**
- ♦ **1N4001 diode**
- ♦ **Microcontroller board** (a Trinket is mentioned, but any can be used)
- ♦ **A metre of wire**
- ♦ **An iron or steel nail**

## SCHOOL OF MAKING



**Figure 3**  
You can't drive a solenoid from GPIO pins, as they can't provide enough power

**GET MOVING**

A solenoid is an electromagnet in which the core is free to move back and forth in the coil to some extent. The whole idea of a solenoid is to convert an electrical signal to linear motion by controlling the voltage on the coil.

This turns out to be a very useful ability. If you ever had an electric model railroad set with electric switches, those were solenoids that were snapping the points back and forth. Other common uses of solenoids are in pinball machines, dot matrix printers, and doorbells.

A solenoid typically has a spring that will return the core to a rest position when the voltage is switched off, or it can use gravity if mounted vertically such as in the doorbell.

Places that sell electronic components often have solenoids. As an experiment, get a solenoid and

**Below**  
Solenoids use the magnetism of inductors to push or pull



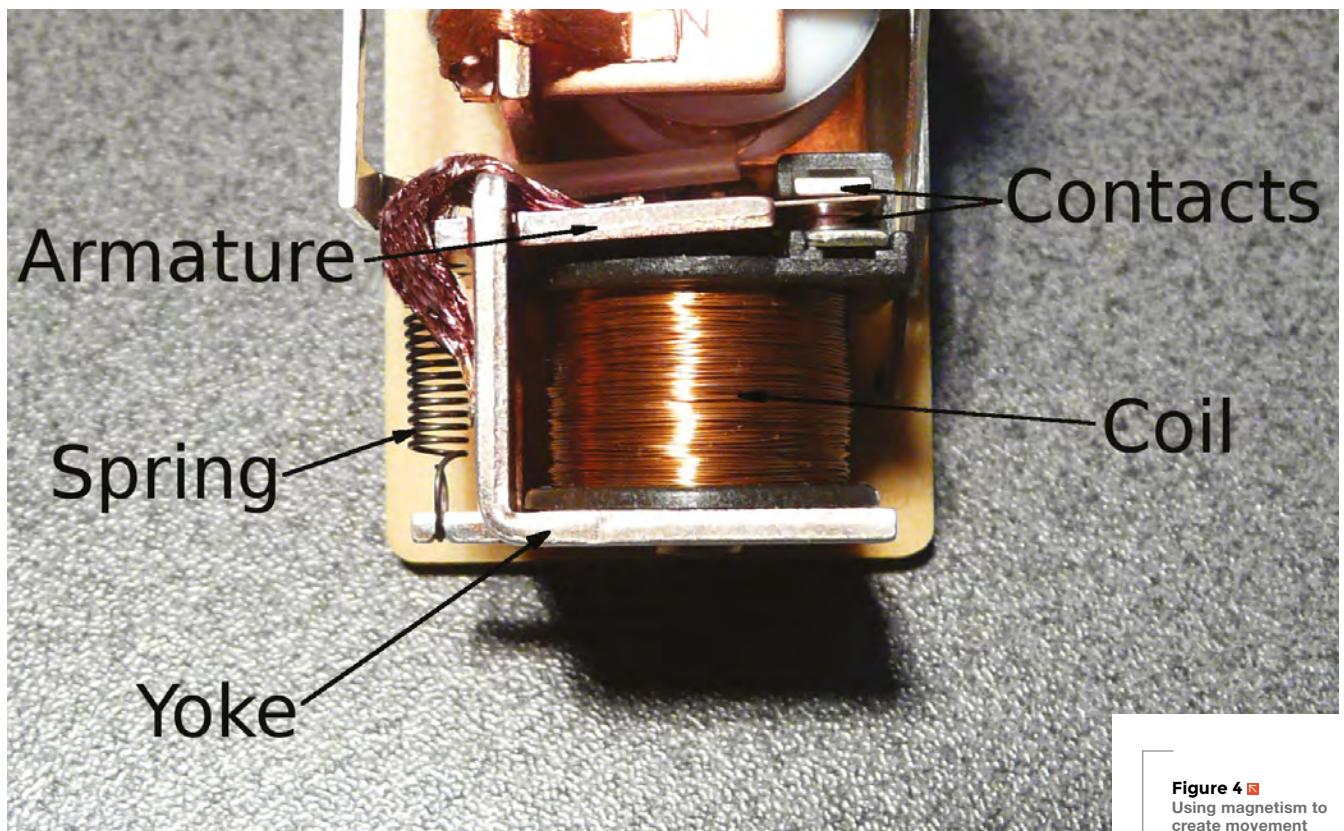
experiment with applying power to it. Solenoids have a voltage rating and you should use that voltage to power it. Keep in mind that they require a non-trivial amount of current; more than a microcontroller board can usually provide. If you want to control a solenoid from a microcontroller board, you'll need to use a driver of some sort. Something like a ULN2803 Darlington driver chip, or individual TIP120 power Darlington transistors. The CRICKIT

**A solenoid typically has a spring that will return the core to a rest position when the voltage is switched off, or it can use gravity if mounted vertically**

board reviewed in issue 8 has drivers for up to four 5V solenoids (or other high current devices). With it you can connect solenoids to your Circuit Playground Express, (or Feather board if you go with the FeatherWing version). **Figure 3** shows the breadboard wiring for connecting a 12V solenoid to a 5V Trinket using a TIP120. Note the diode used to shunt the induced voltage.

**SWITCHING AROUND**

A relay is much like a solenoid that has its moving core attached to a switch. Applying a voltage to the coil causes the switch to change state. Relays are generally used to allow a low voltage signal (like from a 3.3V or 5V microcontroller output pin)



**Figure 4** Using magnetism to create movement

to control a significantly higher one, even up to mains voltage, e.g. a lamp or fan. Another use is to electrically isolate the controlling circuit from the controlled one. **Figure 4** shows the internals of a typical relay. Note the coil that creates the magnetic field, and the armature that is moved by the field and causes the contacts to move. Also note the spring that returns the armature to its resting position, just as with a solenoid.

Relays are easy to find wherever electronic components are sold. You use a relay the same way you use a solenoid. Some come packaged on a board with support circuitry that allows you to use a low voltage/current signal to control them. These can be connected directly to a microcontroller board. For relays without that circuitry, you'll need to use a driver, as with solenoids.

You can replace the solenoid in **Figure 3** with a 12V relay since they work the same way. ↵

## RF CIRCUITS

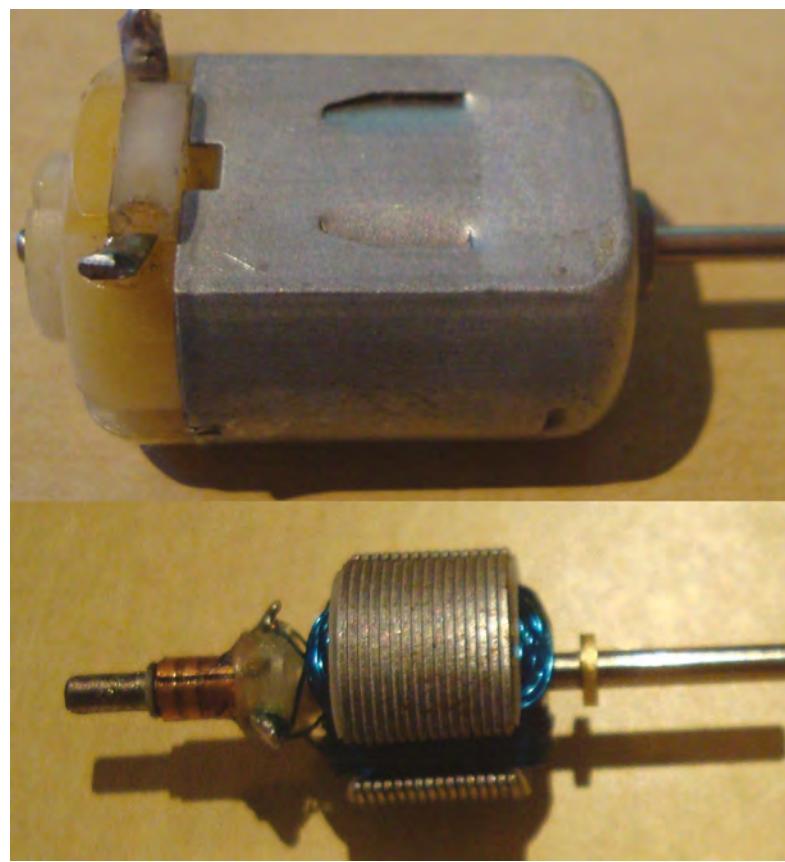
The arcane mysteries of RF electronics are beyond the scope of this article. It's easy to bypass the complexities entirely as you can get pre-built modules. However, if you're interested, look at our feature in issue 6 for more information on how to get started.

Relays are easy to find wherever electronic components are sold. You use a relay the same way you use a solenoid



Above Electromagnets can lift heavy weights. This one is rated for 25kg

## SCHOOL OF MAKING



**Figure 5** Inside this motor, you can see the wire coil that powers it

### SHOUT IT OUT LOUD

A classic speaker can be thought of as an inside-out solenoid. Instead of the core moving in response to the magnetic field generated by the coil, in a speaker the coil moves due to its magnetic field interacting with that of a permanent magnet.

An audio signal is applied to the coil which causes the generation of a fluctuating magnetic field. This field interacts with the fixed field of the magnet, causing the coil to move. This moves the attached diaphragm which generates vibrations in the air, i.e. sound. In this way, we can convert a signal that's an electrical current

### POWER CONVERSION

Power conversion circuits, especially, show the usefulness and versatility of inductors. Pretty much any electronic device you plug into the wall will have one or more inductors at its heart. Linear power supplies will have a transformer to reduce the mains voltage to something more usable. Switching power supplies work very differently, but also have an inductor as a central component. When using batteries, you might make use of a buck or boost power converter to reduce or increase the battery voltage to a value needed by the circuit. These are specific forms of switching supplies.

varying in voltage in time with the music to an actual sound wave we can hear.

### SPINNING AROUND

Above, we discussed how a solenoid uses a coil and its magnetic field to generate linear motion. A motor uses it to generate rotary motion; i.e. a solenoid moves something back and forth, while a motor makes something spin.

DC motors can be treated electrically very much like a solenoid or relay. You can use the same driver method with them (e.g. a TIP120), using a shunt diode in the same way. This suffices to have the motor spin in one direction. One different thing about a motor is that the speed of the spin is useful

“ Motors work using the same principles of magnetism and induction as we've seen with solenoids and relays. In the case of motors, there are multiple coils and multiple magnets involved ”

to control. Solenoids and relays are simply on or off, but a motor can spin at a range of speeds. This can be accomplished by using a pulse width modulation (PWM) signal to control the driver. This is a digital signal that switches off and on very quickly, and the proportion of time the signal is off or on denotes the speed. The other difference with a motor is that it can be useful to control the direction of the spin. This is a bit more involved, typically requiring four drivers arranged in what's called an H-bridge. See

[hsmag.cc/CQkahO](http://hsmag.cc/CQkahO) for more details. The previously mentioned CRICKIT boards include support for driving two motors with speed and direction control.

Motors work using the same principles of magnetism and induction, as we've seen with solenoids and relays. In the case of motors, there are multiple coils and multiple magnets involved. A motor modulates the fields generated by the coils and uses magnetic attraction and repulsion to push and pull against an arrangement of fields from permanent magnets. Since the coils are arranged around a freely spinning axle, this orchestrated push and pull has the effect of spinning the axle and coils. Controlling the strength and polarity of the fields is what allows the control of speed and direction. **Figure 5** shows a

simple toy DC motor, inside and out. See [hsmag.cc/zzFKSg](http://hsmag.cc/zzFKSg) for more details.

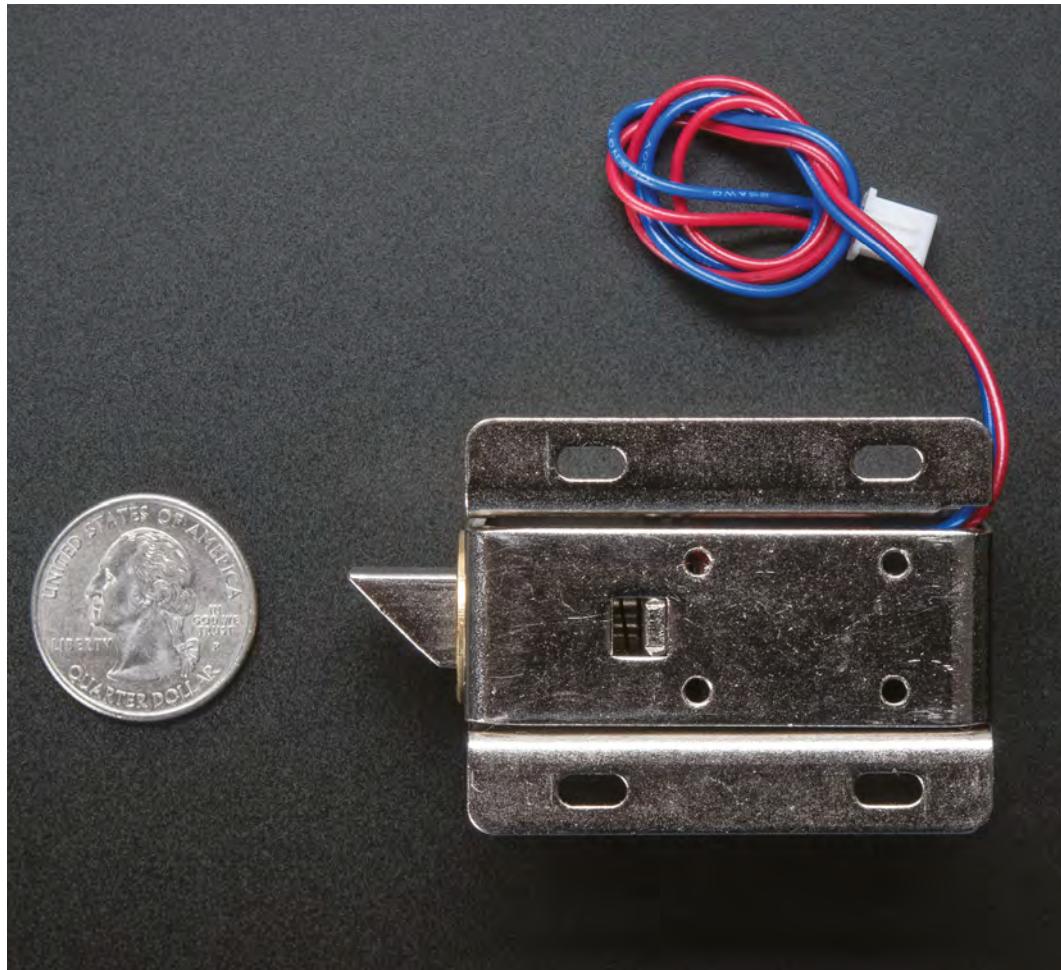
While DC motors are electrically very similar to solenoids and relays, you can use an H-bridge and a PWM signal to control their direction and speed.

Inductors are arguably the simplest electronics component – really, they're just bent wire. But that simplicity belies their usefulness. From current filtering to creating motion, you're probably surrounded by inductors right now, and without them, many of the more complex components wouldn't function. They sit at the bridge between two complex and sometimes hard to fathom areas of physics: magnetism and electronics, and as such, can be a little tricky to understand. Fortunately, much of the hard work has been done for us, and as long as we've got a basic understanding of how they work, we can pick up pre-packaged inductors for any of our needs, be they magnetic, kinetic, or electronic. □

## GET MAKING

Inductors are just about the only electrical component that it's possible to make at home. You can't fabricate a chip or LED without going to phenomenal lengths, but twirl a piece of wire and you've got an inductor. Here are a few of our favourite home-made products.

- FM transmitter: [hsmag.cc/IRlaiL](http://hsmag.cc/IRlaiL) (check local radio power restrictions before making)
- A speaker : [hsmag.cc/vYkXcT](http://hsmag.cc/vYkXcT)
- Electric motor: [hsmag.cc/LglhrT](http://hsmag.cc/LglhrT)
- Tesla coil: [hsmag.cc/NVRXiY](http://hsmag.cc/NVRXiY) (make sure you understand the dangers involved in high-voltage electronics before embarking on a build like this)
- Linear PCB motor: [hsmag.cc/GoySvG](http://hsmag.cc/GoySvG)



**Left □**  
You can get solenoids in different shapes, such as this lock-style one from Adafruit

# Maker's Toolbox: Angle grinder

Cut, grind, and sand your way through almost anything



**Ben Everard**

@ben\_everard

Ben loves cutting stuff, any stuff. There's no longer a shelf to store these tools on (it's now two shelves), and the door's in danger.

**A**ngle grinders are one of the most iconic tools. The spinning wheel, accompanied by a shower of sparks as the wheel digs into steel, is a classic image of metalworking. It's also one of the more intimidating tools in the maker's arsenal – discs spinning at over 10 000 revolutions per minute that are capable of cutting through stone can make short work of flesh and bone.

At its most basic, an angle grinder is just a motor that you can attach discs to. Different discs let you cut through or grind down metal, stone, and other



materials. With other attachments, you can sand or polish to create the perfect finish.

Angle grinders come in a few different sizes denoted by the size of disc they can take. In general, they're sized in imperial units, so we'll stick with that convention here. 4½ inch (115 mm) is the most popular, and capable of most general tasks. For bigger cuts you can get 9 inch (230 mm). There are also other sizes (such as 5 or 7 inch), but they're less popular, and it can be harder to get discs for them. Beyond this, you can get disc cutters that are basically just souped-up angle grinders that can take 12 or 13 inch discs.

There's not a whole lot to an angle grinder. The disc should be secured in place with a threaded bolt, and there should be a guard that you can position to ensure that sparks and debris are reflected away from you as you use it. There should also be a handle that you can position on either side of the grinder to give you a solid double-handed grip when cutting.



**Left** ◆

The central nut unscrews to allow you to change disc

## TICK TICK TICK...

When setting up and using an angle grinder, always consider that there's a risk that the disc could explode at any time. This isn't common – in fact, it's quite rare – but it does happen. Where's the disc going to go? Hopefully, the answer is the guard will shuttle it safely away from the user, and not in the direction of anyone else. If that's not the answer, then you need to adjust the guard until it's set up correctly. This isn't a question of skill – discs can shatter for experienced users as well as beginners, so you shouldn't get complacent.

**“Wood-cutting blades are available, but, frankly, they terrify us and we simply can't recommend them to anyone not experienced enough to be able to decide the risks for themselves”**

The most important part of using an angle grinder is using the right wheel for the job. Different wheels can be used in different ways. Thin cut-off wheels are only for cutting – never put a force into the side of these discs as they're not strong enough and can break. Thicker grinding wheels allow you to grind on the side and can be used to shape metal. Whichever wheel you're using, first inspect it to make sure it's not damaged, then give it a spin in a safe place. Start with

## DISC SIZES

The only obvious difference between the different sized grinders is the size of the removable guard. With this taken off, you can fit, for example, 9 inch discs on a 4 ½ inch grinder. However, just because it fits doesn't mean you should do it, as there's a big difference under the hood. The smaller grinders spin much faster than the larger ones. Basically, this is because you want a particular speed for the outer cutting edge of the disc. If the disc is twice as big, it'll get that speed at half the rpm as a smaller disc, and so larger discs are rated for a smaller number of RPMs.

Putting a large disc in a small angle grinder will spin it too quickly and this could cause it to shatter. Given that the guard will have to be removed for the disc to fit in, this is a dangerous situation, so always use the right-sized disc for your angle grinder.

## SAFETY

Angle grinders are powerful tools spinning fragile blades, throwing up bits of metal and stone. You need to protect yourself before starting up. At the very least, you should have a dust mask, goggles, gloves, and ear defenders. Ideally, you should also have a face mask (over your safety goggles). Grinders can kick out a lot of sparks, so make sure that these aren't going to set your clothing (or anything around you) on fire.

Always make sure that your guard is properly fitted and adjusted (yes, we know YouTube is full of people grinding without guards, but it really is worth using), and that your holding the grinder securely. As well as protecting yourself, make sure that you're not going to be a danger to anyone else around you.

Beyond this, grinder safety really comes down to making sure that you're using the discs correctly, so make sure that you're aware of the proper procedure for your hardware.



very gentle pressure until you get a feel for the wheel and the material and always follow the manufacturer's advice, particularly about the material it's suitable for, and the maximum speed the disc can run at.

Wood-cutting blades are available, but, frankly, they terrify us and we simply can't recommend them to anyone not experienced enough to be able to decide the risks for themselves.

## OUR GRINDER

We tested out a Makita GR4530R 4 ½ inch angle grinder. It's got a 720 watt motor that spins up to 11 000rpm. This is a good size and power for hobbyist users. It'll cut through metal and stone, yet still be light enough to use easily. At £59.99, it's not the cheapest angle grinder available, but it is sturdy enough to stand up to regular use. □

### Above

When using the angle grinder, the guard should protect the user from the wheel

### Below

Angle grinders are simple tools: the only control here is the 'on' button



# Making the most of Tinkercad Circuits

Prototype electronics virtually (and easily) with this free simulation tool

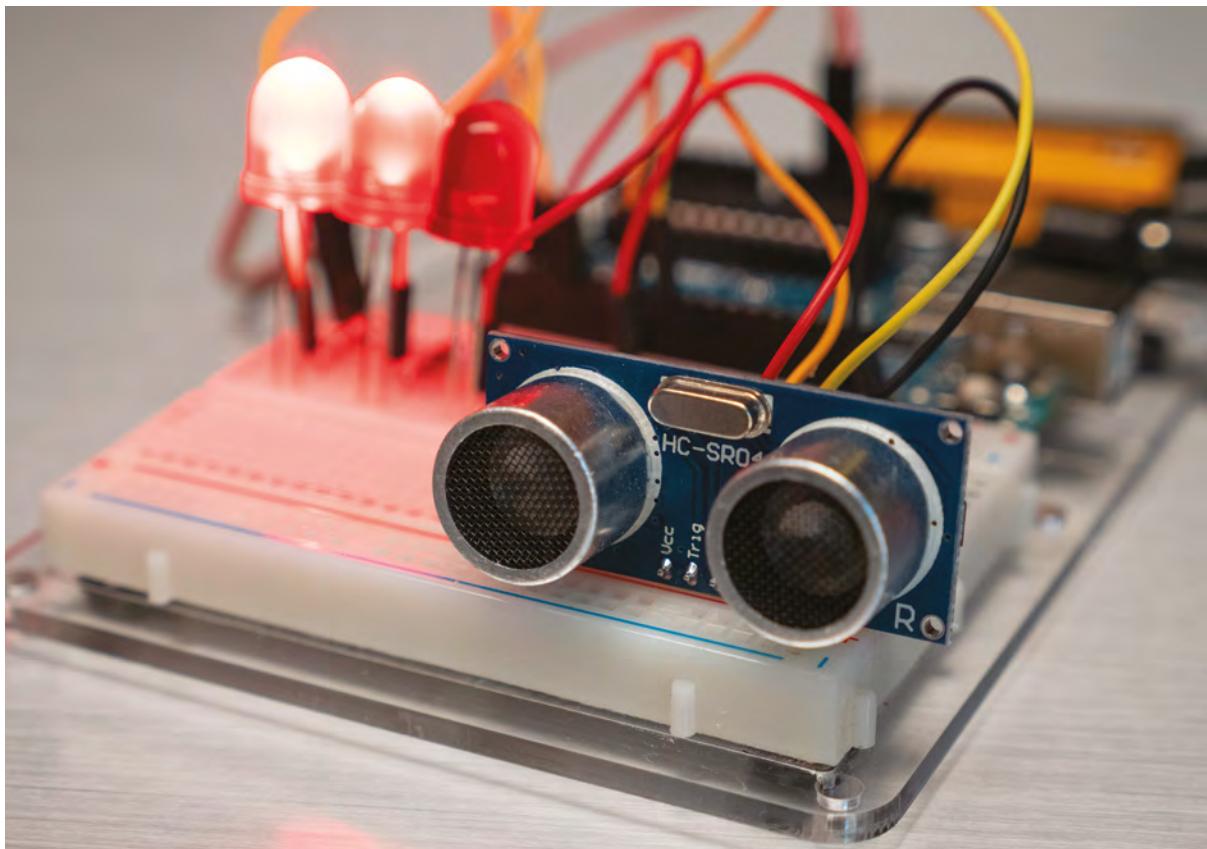


**Becky Stern**

@bekathwia

Becky Stern has published hundreds of DIY tutorials and videos about everything from microcontrollers to knitting. She lives in NYC and you can find her online at [beckystern.com](http://beckystern.com).

**Right ↗**  
Deploying your design to a physical board is easy with the wiring and code already prepped



## YOU'LL NEED

- ❖ Computer with access to the internet
- ❖ Chrome or Firefox browser
- ❖ Tinkercad account [tinkercad.com](https://tinkercad.com)

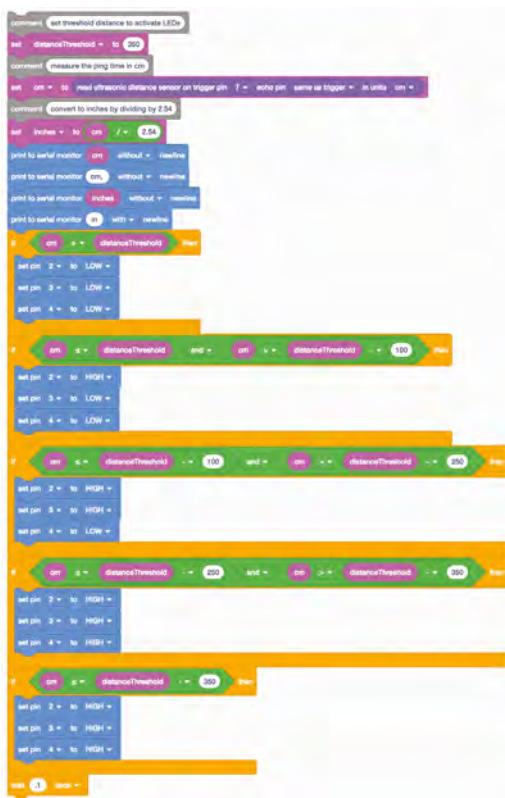
# W

hen you're breadboarding up a circuit, it can be tough keeping track of the wire connections, diagram, and code files.

Tinkercad Circuits helps you design, code, build, and share your electronics projects from your web browser. You drag and drop components, click to connect them up with wires, add some Arduino code (if your circuit calls for it), and click a button to watch your design come to life. Whether you want to prototype away from your toolbox or just want a tidy way to put

diagrams in your project documentation, this guided tour will get you started with Tinkercad Circuits.

In order to fully demonstrate this powerful tool, let's build a simple sensor and LED circuit. Create a free Tinkercad account if you haven't already, and create a new circuit from the Circuits dashboard. On the right of the Circuits editor, there is a panel full of components. You can expand the list with the drop-down menu at the top to see all they have to offer – sensors, switches, motors, Arduino Uno and ATtiny microcontrollers, transistors, batteries, and common ICs, just to name a few.

**Above**

This blocks code is a simple proximity alarm

Drag an Arduino Uno board and breadboard into the workplane. Hover over connection points to see their labels. Click the Arduino's 5V connection point to create a wire from it, and click a connection point on the (+) rail of the breadboard to complete the wire. Double-click along the wire to create bends, then drag them to tidy it up. While selected, you can use the number keys on your keyboard to cycle through different wire colours, or find the colour selection drop-down menu in the blue inspector. Repeat the process to create a wire connecting Arduino's GND pin to the breadboard's ground bus.

**DRAG AND DROP**

Find the LED in the components panel and drag three to the breadboard in the workplane, spaced a couple of rows apart. Change their colours with the part inspector if you feel like it! Drag and drop a resistor to connect the LED cathode to ground, and adjust its value to 220 ohms using the part inspector. Copy and paste the resistor to create two more – one for each LED. Create wires to connect the LED anodes to Arduino digital pins 2, 3, and 4 (**Figure 1**).

Feel free to use any sensor you find in the components panel, or follow along using an

**THE SERIAL MONITOR**

When using an Arduino board, the serial monitor is a way to listen to what's going on in your program by reporting back to the computer over the USB cable. In the Tinkercad Circuits simulator, the serial monitor can be found at the bottom of the Code panel (**Figure 3**, point 4). This can be extremely useful for diagnosing and solving problems with your code. In this tutorial's example circuit, printing to the serial monitor helps you observe the distance change more granularly than the LED states show alone. Tinkercad Circuits also has built-in graphing of your serial data, provided the stream doesn't have any text in it. This is handy for visualising changes in sensor readings and other inputs, as well as for tracking variables in your program. With the serial monitor open, click the graph button (**Figure 3**, point 5) to open the graph panel. When the simulation is running, you should see the graph values change as you interact with the sensor.

ultrasonic distance sensor. This proximity sensor uses sound waves to bounce off objects, much like a bat's echolocation. Find the ultrasonic distance sensor of your choice (there's a three-pin type and a four-pin type) and drag it into the workplane, to an unused section of your breadboard. Wire 5V to power (+), GND to ground (-), and SIG or TRIG to Arduino pin 7. Four-pin users should also connect the ECHO pin to Arduino pin 6 (**Figure 2**, overleaf).

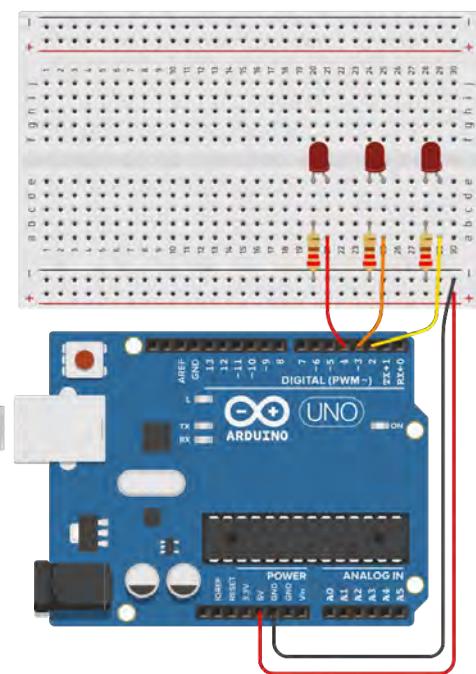
**SPRINKLE ON SOME CODE**

Next, it's time to program the Arduino to listen to the sensor, evaluate its reading, and light up some LEDs accordingly. Find and click the Code button to expand the programming panel. →

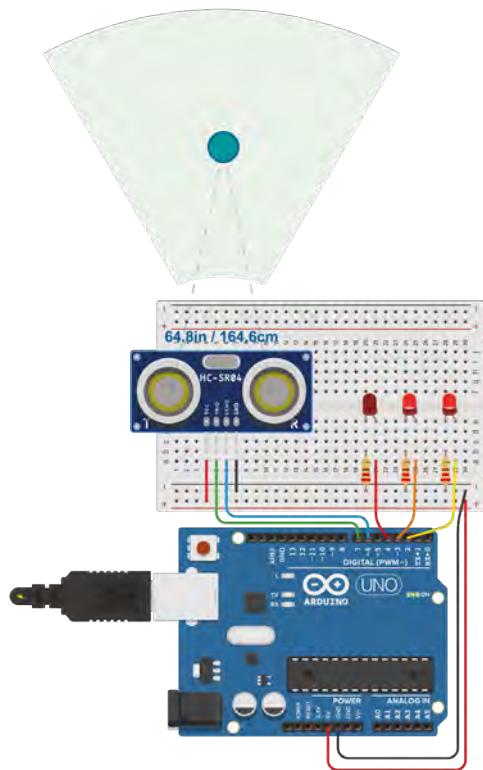


**Figure 1**

You don't need to build on a breadboard in Tinkercad Circuits – you can free-wire components if you prefer. But if you plan to build a physical version of your project, building on a breadboard can help your circuits look the same



## TUTORIAL

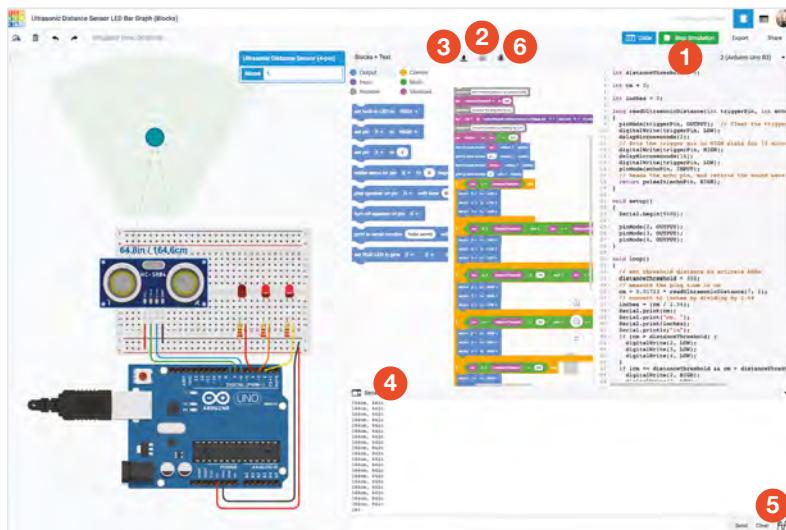


**Figure 2** Each sensor has a way to simulate its input, like the dragable blue circle in front of the ultrasonic distance sensor

**Figure 3** Prototyping perfection

The default view is for coding with Scratch blocks, which is a beginner-friendly way to get started with programming. Find the drop-down menu on the left and select ‘Blocks + Text’ to see the Arduino code generated by the code blocks, or select ‘Text’ to change the way you compose the code for your Arduino board to regular old text coding, like you would use in the Arduino software IDE.

Either way you choose to create your program, you’ll want to create a variable to set a certain distance threshold, and another to store the sensor



## VIRTUAL INSTRUMENTS

So much can be gleaned from your circuits by adding a little instrumentation! The multimeter and oscilloscope components add an invaluable insight to your design and debugging processes. Whether you’re trying to learn more about series and parallel circuits (**Figure 4**), or visualise the PWM signal for a fading LED, these two virtual tools are just as useful as the real thing.

reading in centimetres. To convert centimetres to inches, divide by 2.54 (optional). Print your sensor value to the serial monitor, and use ‘if then’ statements to evaluate for different ranges of distance between 0 and 350 cm, lighting up more LEDs the closer the object is to the sensor.

Click the Start Simulation button (**Figure 3**, point 1) to power up your circuit and run the Arduino program. Click on the sensor to show its interaction interface, and drag the blue circle closer and further away. Notice the numbers printed on screen changing and the LEDs lighting up in relation to distance.

In text-only coding mode, you can click the file drawer button (**Figure 3**, point 2) to view the common Arduino code libraries included in Tinkercad Circuits. It’s possible to use libraries not listed, by pasting the contents of the library file(s) into the Arduino sketch itself.

## LET'S GET PHYSICAL

To bring your circuit into the physical world, follow the diagram you created to build up a breadboard circuit, and grab the code by copying and pasting it into your Arduino IDE or downloading the sketch

## IT DOESN'T HAVE THE PART I WANT!

Because Circuits is a simulation environment, the library of parts is not huge or user-extensible (like [Fritzing.org](http://Fritzing.org)). Its components are more than marked-up graphics: they’re designed to behave like the real components they represent inside the physics simulation, so they are complex to create. That fact, combined with the beginner-focused mission of Tinkercad, equates to a limited palette of components that is not suitable for all projects. But the team does aggregate parts requests that come in via the Tinkercad Help Center. One way around a missing part is to leave a space in your design for the component, and mention it in the circuit’s description.

## ARDUINO LESSONS IN TINKERCAD CIRCUITS

So far on the Tinkercad Circuits learning site, you'll find a guided tour to the basics of electronics and the following Arduino skills:

- Blink an LED
- Multiple LEDs and breadboards
- Fading LED (analogue output)
- RGB LED colour mixing
- Push-button (digital input)
- Potentiometer (analogue input)
- Using the serial monitor
- PIR motion sensor
- Photoresistor
- Temperature sensor
- Ultrasonic distance sensor

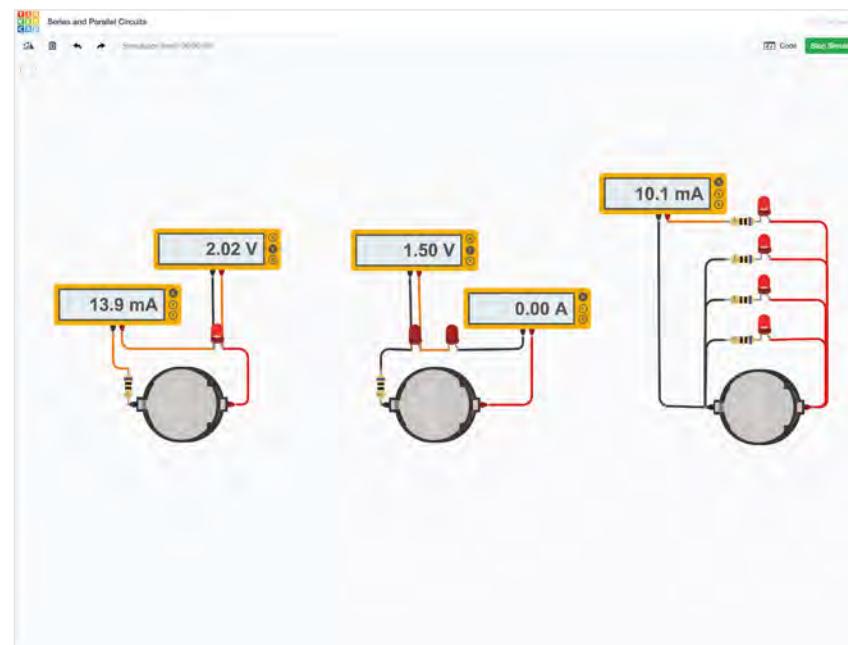
New lessons are added regularly. You can also find these guides on the Circuits account on [Instructables.com](#).

by clicking the button with the downward-pointing arrow (**Figure 3**, point 3). Put the code on your board the way you normally would – plug it in over USB, select the proper board and port in the Arduino settings, and click Upload.

Having a virtual version of your circuit and program is useful as a way to check your work – if the simulation is working but your physical circuit is not, comparing the two can turn up the solution.

### Below

There's a range of projects to help you learn Arduino



## SHARE

To link to your circuit from other sites, make it public. Don't forget to give it a good title and a few tags. Now you can also grab the code to embed the circuit in other pages too, like when composing a tutorial on Instructables. When following somebody else's instructions, a diagram is so much easier to read than a photo of a rat's nest of wires!

Teachers, you can create template circuits for your students to start with by sharing the link and having them click 'Copy and Tinker' on the public design page. You can find the sample circuit used in this tutorial ([hsmag.cc/kICRCRj](#)) and do the same to explore and modify the design. Find more useful and inspirational circuits on the Tinkercad Gallery page.

With all that done and dusted, you're finally ready to go build your own portfolio of rad circuit designs! Build virtual records of the projects on your bench now, and then sketch out projects you want to build in the future. □

**Figure 4**

Your circuit doesn't have to have a microcontroller or code to make a useful simulation. You can learn a lot about series and parallel circuits with a few batteries, LEDs, and a virtual multimeter

## STEPPING THROUGH

There is a special feature in Tinkercad Circuits called the debugger. It steps through your code and allows you to peer in at your variables while the program is running. Any time your code isn't doing what you expect, you can use the debugger to find out more about what's going on. With the code editor open, find the debugger by clicking the button with the bug icon (**Figure 3**, point 6). In Blocks + Text or Text-only mode, click a line number to add a breakpoint, where the debugger will stop each time through the loop. Start the simulation and hover over variable names while paused to see their values. This debugging ability isn't something you can typically do with the Arduino workflow (although it is coming in a future version of the Arduino IDE), so the extra insight is a privilege for beginners and advanced users alike.

# Electrical safety testing

Take the worry out of keeping your power tools safe, as we demystify the PAT test



**Jenny List**

@Jenny\_Alt0

Jenny is the creator of the [@LanguageSpy](#) electronics kit and a key member of Oxford Hackspace.

If you take a look around any office, school, hospital, or other workplace, you should find that each and every electrical appliance will have a little green sticker on its plug. It usually says 'Pass', with a scribbled date and a set of initials, and it denotes that the item in question has passed an electrical safety test. These tests, often commonly known a Portable Appliance Tests (PAT tests – yes, the 'tests' is redundant), are a safety requirement in the UK and many other countries, though you will

often find that there is some confusion about their exact nature and that of the requirement for them. In this article, we'll take a look at the electrical safety test, and offer some advice for the electrical safety of your own appliances based upon nearly 30 years' experience with a PAT tester.

As the name suggests, these tests are designed for portable appliances. Other types of electrical installation require different tests to ensure safety.

You may not have a requirement to keep little green stickers up to date on your bench, but it still



**Right ♦**

The outer layer is there to protect you. Make sure it's doing its job

## WARNING



**Mains electricity is dangerous** – it can and does kill. In this article we're looking at the PAT testing process, which is a useful safety test. However, it doesn't guarantee absolute safety – no test does. While you don't need to hold any electrical qualifications to do this, you should be knowledgeable and competent enough to understand the risks and issues involved. Remember, by performing a safety test, you are assuming responsibility for the safety of yourself and others. Take that responsibility seriously.

While we have endeavoured to provide accurate information, nothing in this article constitutes legal advice – if you're performing these tests, it's your responsibility to make sure that you are in compliance with the current legal requirements in your jurisdiction.

## WHAT YOU WILL NEED

Before you embark on electrical safety testing, you will need a basic set of tools and a few consumables. Bring together everything you might expect to need to open the case of the appliance or wire a plug, so, for example, screwdrivers, wire cutters, and strippers. Then make sure you have some replacement plugs, and for Brits, and other readers in areas with BS 1363 sockets, fuses of all capacities. Set aside a clear and well-lit bench for your tests, and ensure that there is plenty of space. Be very aware of mains safety while you are performing the tests; by their very nature, there is a risk of electric shock should an untested appliance prove to be faulty.

Perhaps unexpectedly you do not need a PAT tester to inspect your appliances for electrical safety, however it makes sense to make use of one if you have it.

does no harm to be familiar with the safety of your tools, as some day it might save your life.

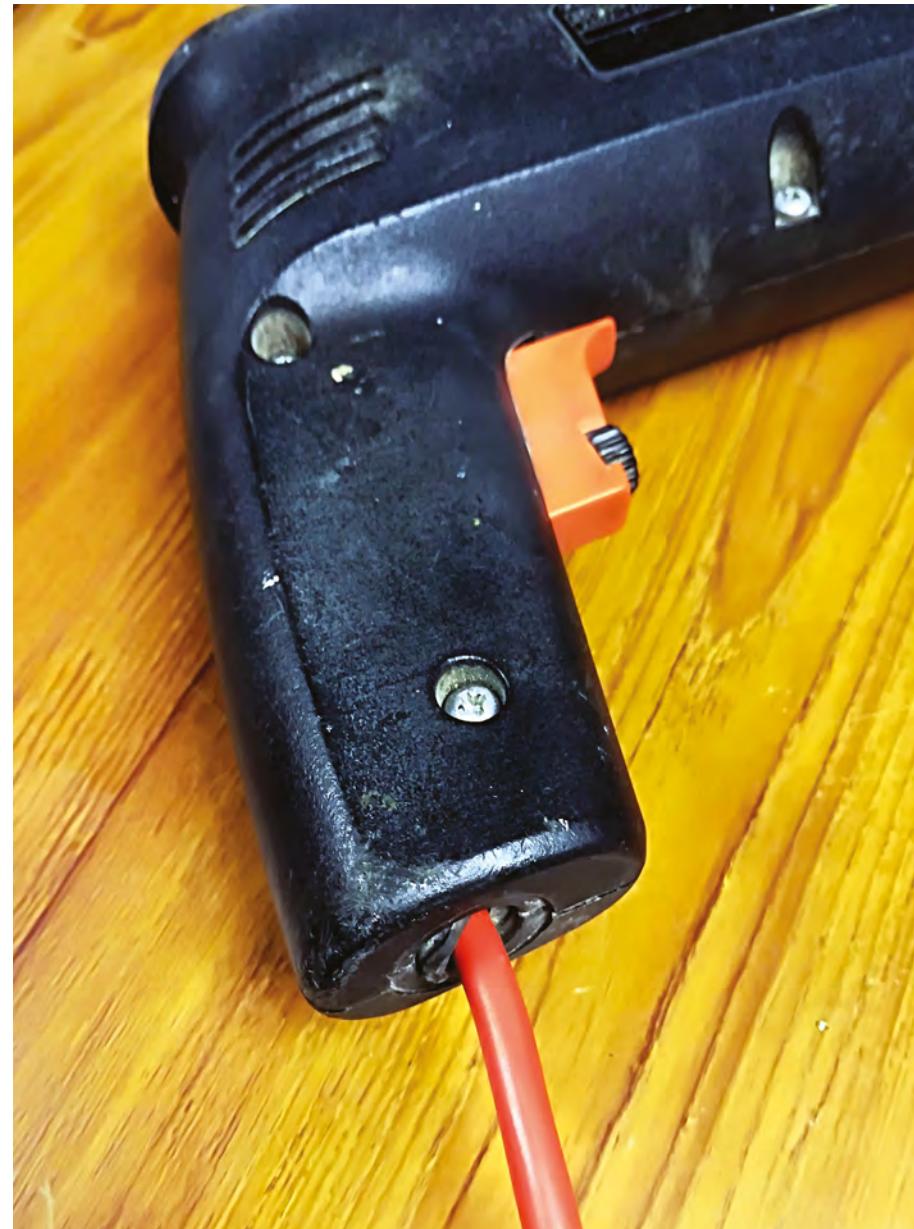
This article covers the process in the UK. In other countries it may vary. The law behind electrical safety testing in the UK is the Electricity At Work Regulations 1989, a document which requires that electrical appliances be both maintained in a safe condition, and inspected for electrical safety

**“ This industry can sometimes  
be responsible for  
unnecessary or inadequate  
products or services ”**

on a regular basis. It doesn't specify how this should be done, but the usual procedure involves a thorough physical inspection, followed by an electrical test with a piece of test equipment called a PAT (Portable Appliance Test) tester, which runs a series of insulation, load, and contact resistance tests. Particularly in the context of bench tools, it is the physical inspection that is the most important part of the process, for an appliance in a physically dangerous state can still pass an electrical test.

### PASS OR FAIL?

It's worth repeating that (in the UK at the time of writing) there is no requirement for a PAT tester to be used, and no specification of who should perform the test, which has created an opening for an entire industry surrounding electrical safety testing, with



little oversight. This industry can sometimes be responsible for unnecessary or inadequate products or services.

An important point about electrical safety testing, to take away from the previous paragraph, is that there is no requirement for a qualification to do it. There are quite a few organisations offering qualifications that are often little more than introductions to a PAT tester, and plenty of clients and employers who demand that testers have them. However, this has no legal basis.

Have you ever watched a professional electrical safety testing company go through a workplace testing all the appliances? There are companies →

**Above** ◁  
The flexible joint  
that should be here  
protects the flex  
from damage

## TUTORIAL

**Right** ♦

This is easy to do,  
but also easy to fix

### WHAT DOES A PAT TESTER DO?

A PAT tester should offer at least three basic tests: insulation, leakage, and earth bond. We'll consider each one in turn. It's not a requirement to use a purpose-built PAT tester to perform these tests, but they're far easier to perform with a proper tester, and this also eliminates a potential source of human error.

The insulation test applies a high voltage in the 600 V range to the appliance, to ensure that there is no insulation breakdown that could expose the user to danger in the event of a high voltage spike. It measures the resistance at the high voltage, which should be in the order of many MΩ.

The leakage test tests for any leakage from the live wire to either the exposed metal components of the appliance or the earth wire, to ensure that no significant current can leak within range of the user.

A small measurable current in the order of less than a couple of mA is considered a pass. An earth bond wire to the PAT tester can be used with this test, clipped to any exposed earthed metalwork to measure leakage current flowing to it.

Finally, the earth bond test looks at the integrity of the connection between the earth pin in the plug and any exposed metalwork on the appliance. The earth bond wire is clipped to the exposed metalwork, and a high DC current in the region of 40 A is passed through it. To pass, the connection should present a very low resistance, and be able to survive the test without burning out.

**Below** ♦

MK Makerspace's PAT tester,  
ready to use



that do a tremendous job, but it's an industry that also has its fair share of dodgy players. These operators are paid on piece work, so their objective is to test the maximum number of appliances in the shortest possible time. A man with an automated PAT tester works through the room at break-neck pace, simply plugging in each appliance and running the automated test, before slapping a sticker on the plug, and moving on to the next one. Any inspection beyond the automated testing is often minimal and, while it seems to be a lucrative job for the testing companies, we're not so certain it does a good job when it comes to electrical safety.

So, we've seen a few of the shortcomings of commercial electrical safety testing, how can we do a better job when it comes to our own appliances?

We're going to use an electric drill as an example when we talk about performing a real-world test, because it is a good representative of an appliance that receives a lot of punishment and thus is likely to have plenty of faults that might fail it. The same inspection and testing routine applies to all appliances, though in some cases some of the things specific to a tool like a drill might be unnecessary.

First, perform an overall visual inspection of the appliance and its cable. You are looking for cracked or broken cases and enclosures, and on the cable you are looking for cracked, cut, split, or otherwise damaged insulation. Don't forget to check any cord grips or strain relief sleeves. On our drill example, it should usually have a rubber strain relief sleeve that should be intact and capable of doing its job. It's important to point out that this is an electrical safety test rather than a general condition test, so it would be possible to have cracked or damaged parts that

## WHAT THAT LITTLE GREEN STICKER REALLY MEANS

As a tester, that little green sticker that goes on the plug when something has passed the test is more important than you might expect. It's not a legal requirement, but as a record of the inspection it's got the date, and the tester's signature on it. That signature makes it in a way a legal document, because what the tester is doing isn't just saying "I did the test", but "I assume liability should anything unfortunate happen with this appliance during the period this test is valid". In simple terms, if you test something that someone injures themselves

with, and it turns out that you missed something, you should reasonably have been expected to find, then you are likely to find yourself in a huge heap of trouble. Take electrical safety testing very seriously indeed, and don't apply a pass to something unless you are really sure it is deserved.

**Below** A selection of test stickers



have nothing to do with electrical safety. In the case of our drill, for example, the side handle, if fitted, has nothing to do with the electrical safety (though it might affect operational safety), but the plastic shell of the tool should not be cracked or broken. If you imagine whether an inquisitive child with a screwdriver could insert it into an opening and reach some volts, that's a good rule of thumb.

### FIXING UP

It's important to state that, while you may fail an appliance for any of these points, there is nothing to stop you making good any defects, such that electrical safety is maintained. For example, you might replace a damaged flex with one of the correct current rating, or you could 3D-print an appropriate

replacement for a broken plastic or flexible part (ensuring that the replacement is strong and insulating enough).

Once you have completed a visual examination, you should move on to the plug. Replace it if it is in any way damaged, if its plastic is cracked or broken, or if its cord grip has ceased to be effective. Plugs are cheap enough to be a consumable in this context.

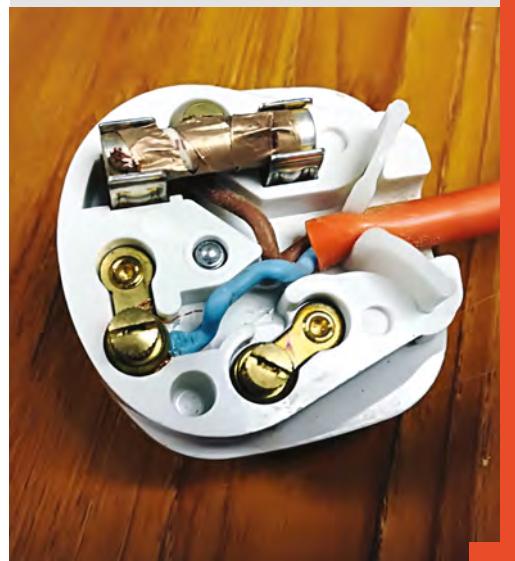
Look at the wiring of the plug, and the fuse. In the first instance, the plug should be appropriately wired, with the correct wires to their respective pins, and the insulation should be stripped back just far enough that the copper should only be within the terminal. The wires themselves should be cut to the right length for each terminal, in the case of most →

BS1363 plugs, this means that the live wire, usually brown, will be shortest, followed by the blue neutral wire, and then the green/yellow wire as longest. If you imagine the flex being pulled out of the plug, the first to leave its terminal should be the live, followed by the neutral, leaving the earth wire connected for the longest.

The fuse in a BS1363 plug should be appropriate for the rating of the cable to the appliance. Its purpose is to prevent fire by blowing before the cable can melt, therefore if a fuse is fitted with a higher rating than the cable, it can present a significant risk. Most BS1363 plugs are supplied fitted with a 13A fuse, and though this shouldn't

### PLUGS MAKE THEM SAFE

Since this is a British magazine, we'll look at the British 230V mains plug, BS 1363. All but very old plugs will have plastic sleeves, and thus be the revised BS 1363A. BS 1363 plugs are unique in the world in having a fuse. The fuse exists because of a quirk of UK house wiring practice, that means some sockets are capable of delivering more current than the plug is rated for, and its purpose is simply to prevent the cable from catching fire in the event of a short-circuit. The fuses for BS 1363 plugs are a standard size, and are available in a range of values. BS 1363 plugs are most often supplied with a 13A fuse, but any fuse should be matched to the cable used. Cable capacities are often moulded into their outer insulation, but if this information is missing, then the current can be derived from the power draw taken by the appliance.



#### Right ♦

Oh, the horror! An example of how not to wire a British plug

happen, a significant number of appliances also come fitted with them, despite having differently rated cables. You will quickly find yourself with a box of redundant 13A fuses as you replace them with the correct values.

### AUTO PILOT

With your appliance, its cable, and its plug in good order, you are ready to move on to the PAT tester. The purpose of the electrical test is to find any non-obvious faults – it is a complement to the visual inspection, rather than the most important part of the whole procedure. It is far more common for an appliance to fail the visual inspection than it is for it to fail the electrical test, if the electrical safety testing regime is properly implemented.

There are PAT testers for many different budgets, from more inexpensive models starting around £200, with a manual selection of tests, through to deluxe versions, with full computer control and built-in inventory management and asset sticker printing. Most will have some form of automation, so the testing procedure itself will often be very straightforward. Make sure to read the instructions for your device. All PAT testers will offer substantially the same range of tests, and we've listed them in the box describing what a PAT tester does.

Assuming you've inspected your appliance and it's passed the test, you can now apply the green sticker, put the date and your mark on it, and call it good. If it fails, there are red fail stickers, and you shouldn't be afraid to fail appliances that cannot be made safe.

The only thing that remains is to ask how long you should wait before returning and testing the appliance again. In most cases this is a year, however that is an arbitrary period and yet again there is no legal requirement for it, only that the tests be done on a regular basis. It is probably best to perform the test on a frequency based upon the purpose of the appliance. A desktop computer or laser printer will not see rough service and does not need testing as frequently as a workshop power tool, for example. You should at least perform a visual inspection of a hand-held drill or similar every few weeks, because a year is a lot of time for dangerous faults to appear.

We hope this has given you an introduction to electrical safety testing, and that your bench or workshop will now be a safer place for it. If you take care of your power tools, they will reward you with long, faithful, and above all, safe service. Make amazing things with them! □

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# Making a 3D pen dragon

Taking sketches to the third dimension



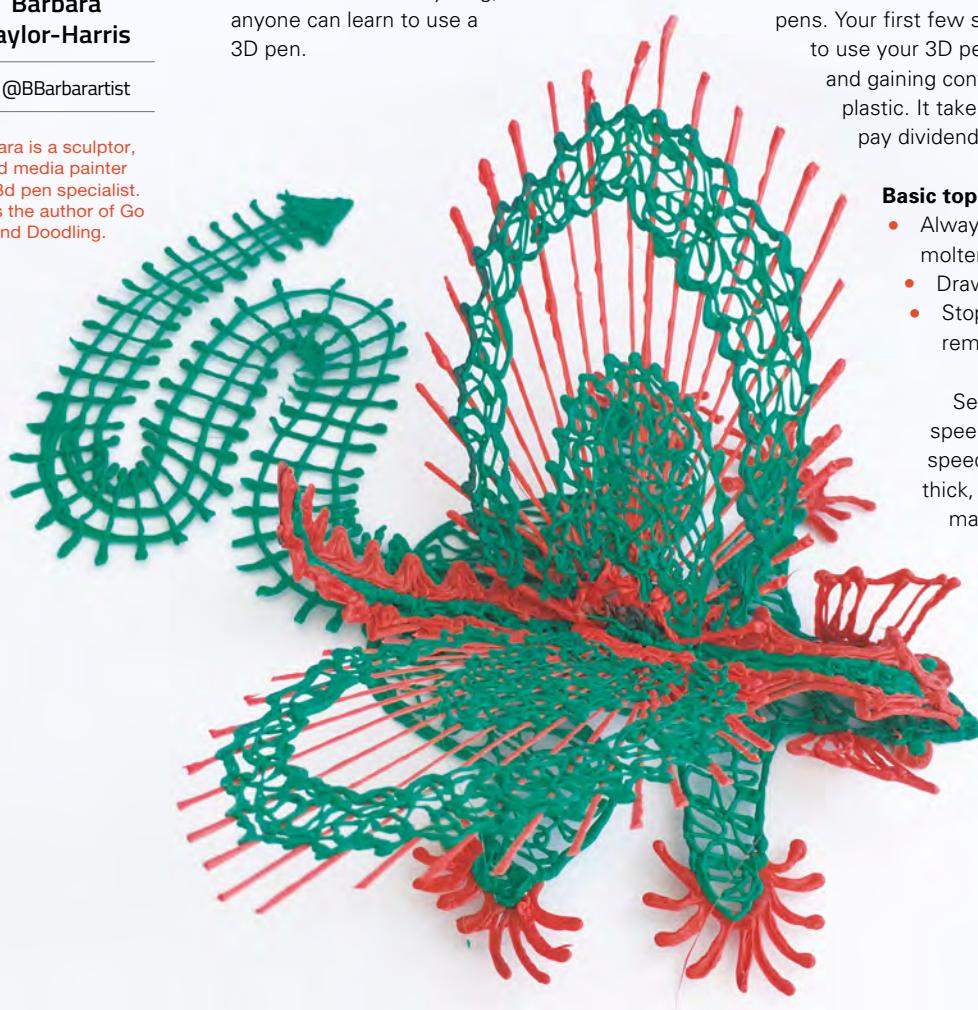
Barbara  
Taylor-Harris

@BBarbarartist

Barbara is a sculptor,  
mixed media painter  
and 3d pen specialist.  
She's the author of Go  
Beyond Doodling.

A

lthough the 3D pen was introduced as a toy, it has become a useful drawing, design, and construction tool. With imagination and practice, it is possible to design and make almost anything, and anyone can learn to use a 3D pen.



The basic techniques that we'll go through here are: drawing lines, simple infill methods and some basic joins. With these, you can design and sketch your own 3D objects.

Working with a 3D pen is similar to when you learn to draw and write with crayons, pencils, and pens. Your first few steps need to be learning how to use your 3D pen by practising drawing lines and gaining control. You are drawing with liquid plastic. It takes a little while, but practise will pay dividends.

#### Basic top tips:

- Always draw away from the molten plastic
- Draw slowly and steadily
- Stop, and then wait before removing the pen

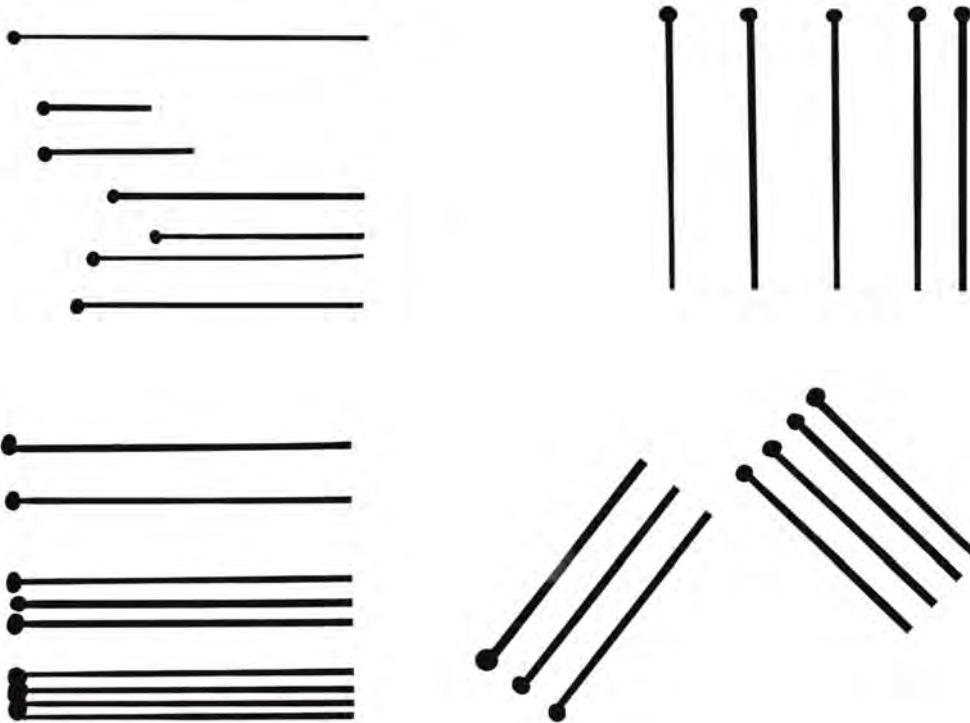
Set your pen to the slowest speed. Drawing slowly at a slow speed should give you a reasonably thick, strong line. The trick is to master matching your drawing speed to the extrusion speed of the pen. You are aiming to create even and consistent lines.

#### LINE PRACTICE

##### 1. Anchor and draw away

Always press your pen down to your drawing surface. Hold the pen in one

Left ◇  
The completed  
3D dragon!



place to extrude a small blob to anchor the strand. This will hold the plastic and enable you to draw away slowly.

## 2. Straight Lines

Follow the short lines horizontally, tracing the pen line and using the template lines as a guide to help you. Do this a few times and then turn the template and try drawing vertically and diagonally. Try with and without the metal ruler.

## DRAWING THE DRAGON'S WINGS

Draw the outline and then the veins of the wings. Use the metal ruler to guide your pen on the long lines. Draw along the edge of the ruler as you would with any pen or pencil.

To give the wings more strength, two sections use the filigree or lace fill you used on the spine decoration.

This time try drawing with long continuous lines, lifting slightly when you cross another line. Adding more lines and fewer gaps will make the wings stronger but also denser.

When you remove the wings from the tracing paper you will have the drawn side and a smooth side; I usually put the drawn side to the inside when I attach the wings to the dragon's body. →

## YOU'LL NEED

- ◆ 3D pen
- ◆ Filament

**Left ↗**  
Use these practise lines to get to grips with your pen

## BASIC EQUIPMENT

### A 3D pen

There are over 250 pens on the market. Starting off, I advise you to choose one at a lower price to try and see if you like it before spending more.

### Some filament

To begin, I suggest you use PLA filament as it has no fumes or odour, and is biodegradable. About twenty metres of one colour.

### Good quality tracing paper

You need this over the template to protect it so you can use it several times.

### A metal ruler

This will help you draw straight lines. Foam-backed rulers are useful because they give you a little height above the template.

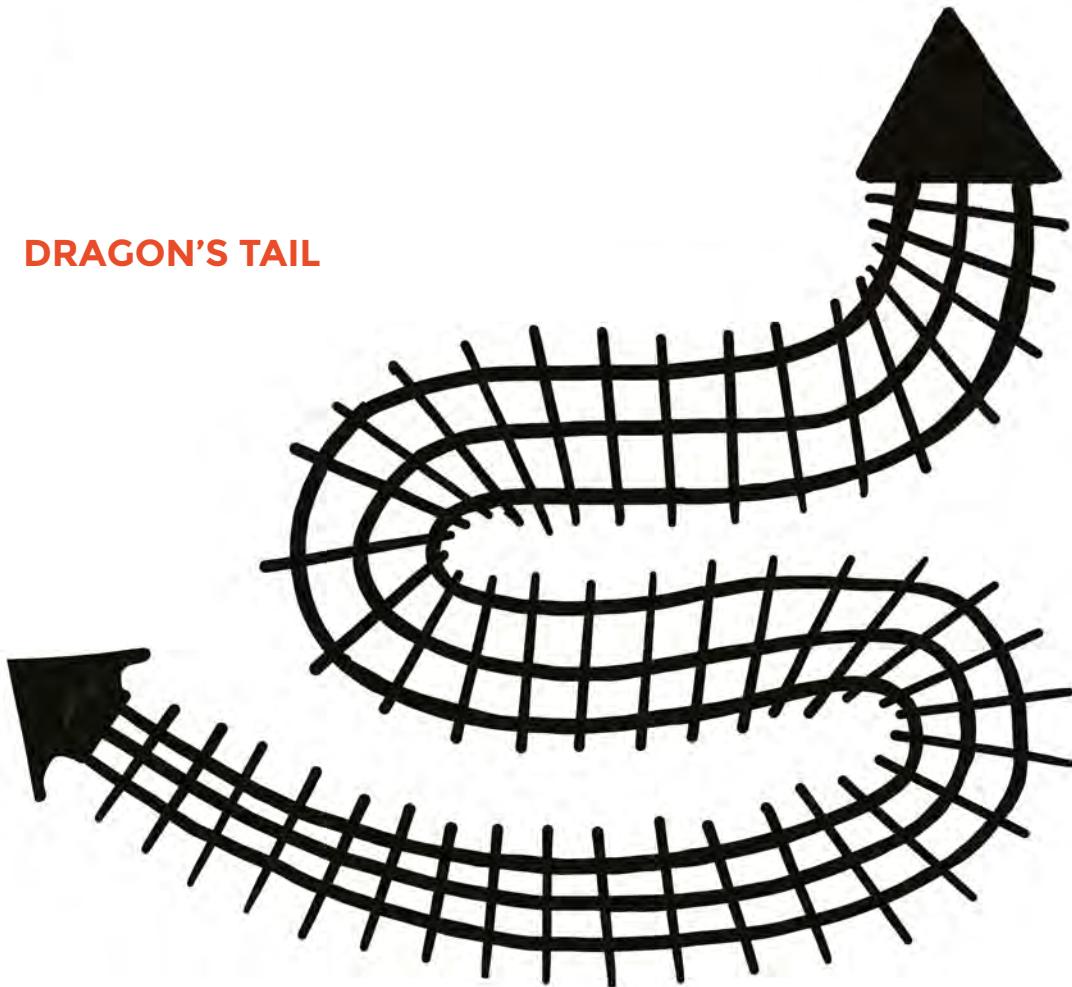
### A board/mat

You will need something heatproof to protect your work surface.

### Sharp scissors or cutters

You always need to cut a straight end to the filament before feeding it into the 3D pen.

### DRAGON'S TAIL



#### DRAWING THE DRAGON'S TAIL

All lines must join for the plastic to fuse together. Draw the outlines and the centre lines of the tail first.

Start at the tip of the tail and work downwards, then go back and add the crossing lines.

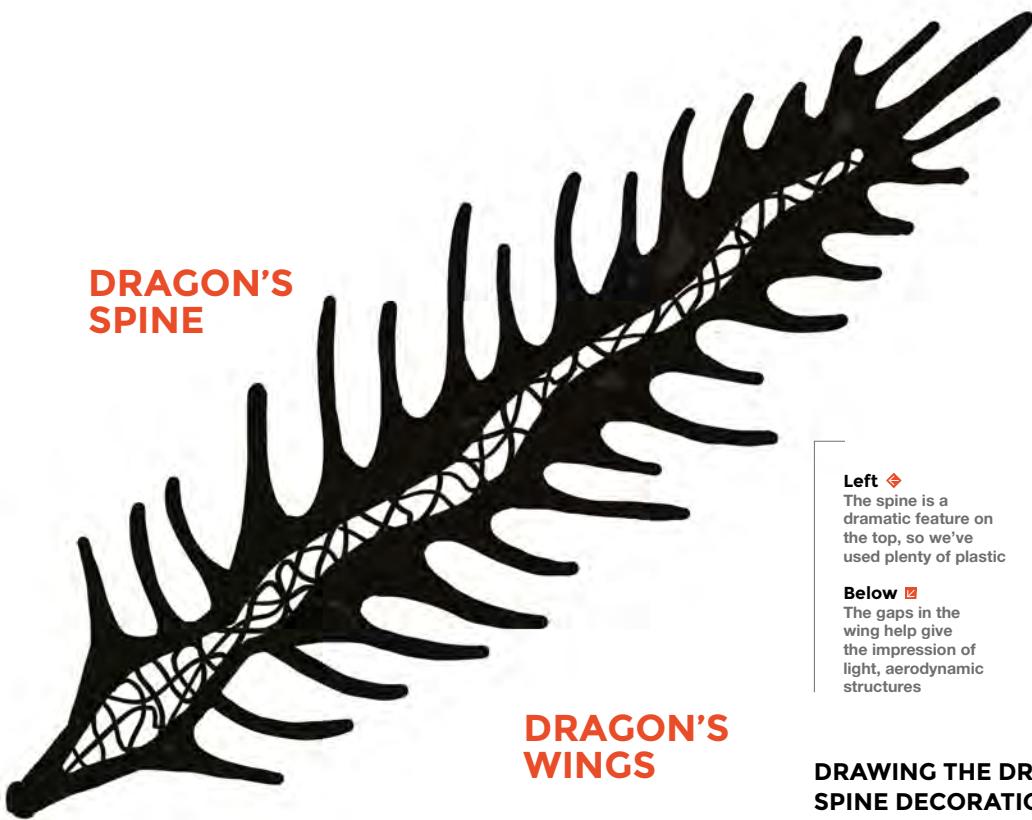
You can make thicker lines and completely fill the top and bottom of the tail by drawing lines touching each other. The spaces between the lines on the tail will help to make it flexible.

**Above ↗**

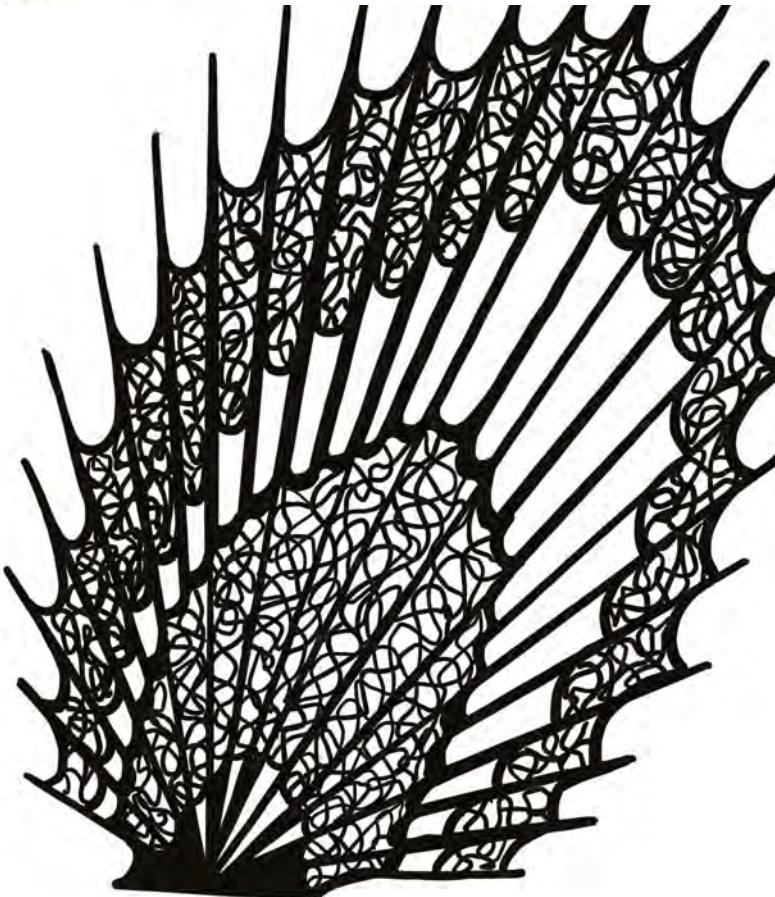
The cross-hatch of the tail gives both texture and rigidity

#### COLOURS

One great thing about 3D pens is that it's quick to change colours. Just swap over the filament and pick up where you left off. We did the dragon in green and red, but you can use whatever colours you like. Get creative! You don't have to limit yourself to colours: you can also get metallic and glow-in-the-dark options. The only limit is your imagination (and the laws of physics, but mostly your imagination).



## DRAGON'S WINGS



### Left ↗

The spine is a dramatic feature on the top, so we've used plenty of plastic

### Below ↘

The gaps in the wing help give the impression of light, aerodynamic structures

## DRAWING THE DRAGON'S SPINE DECORATION

Draw the outline first. Then draw the inner edge of the solid area. Leave the middle blank and carefully fill in the outer shape by making small circular motions with your pen set to slow speed or fill the outer shape by using lots of small lines close together.

If you have gaps you can repeat the process and fill the gaps afterwards.

To fill the middle section and give some rigidity to the shape, we use a filigree or lace infill technique. These lines join the sections together to give the shape strength.

The key is to anchor to one edge and then follow the line to the other side, ensuring all the lines touch and fuse together. Alternatively you could bridge across the gap with straight lines.

## DRAWING THE DRAGON'S WINGS

You'll need two of these. Draw the outline and then the veins of the wings. Use the metal ruler to guide your pen on the long lines. Draw along the edge of the ruler, as you would with any pen or pencil.

To give the wings more strength, use the filigree or lace fill you used on the spine decoration.

This time try drawing with long continuous lines, lifting slightly when you cross another line. Adding more lines and fewer gaps will make the wings stronger, but also more dense.

When you remove the wings from the tracing paper you will have the drawn side and a smooth side, I usually put the drawn side to the inside when I attach the wings to the dragon's body. ➔



**DRAGON'S BODY**

**Above ↗**  
You could easily adapt this design to be any other reptile

### DRAWING THE DRAGON'S BODY

The pattern on the dragon's body uses lines and filigree infill. Draw the outline first, then the internal solid lines. Finally, add the infill. Remember to be sure that all lines join to the outline and/or each other.

### ASSEMBLING YOUR DRAGON

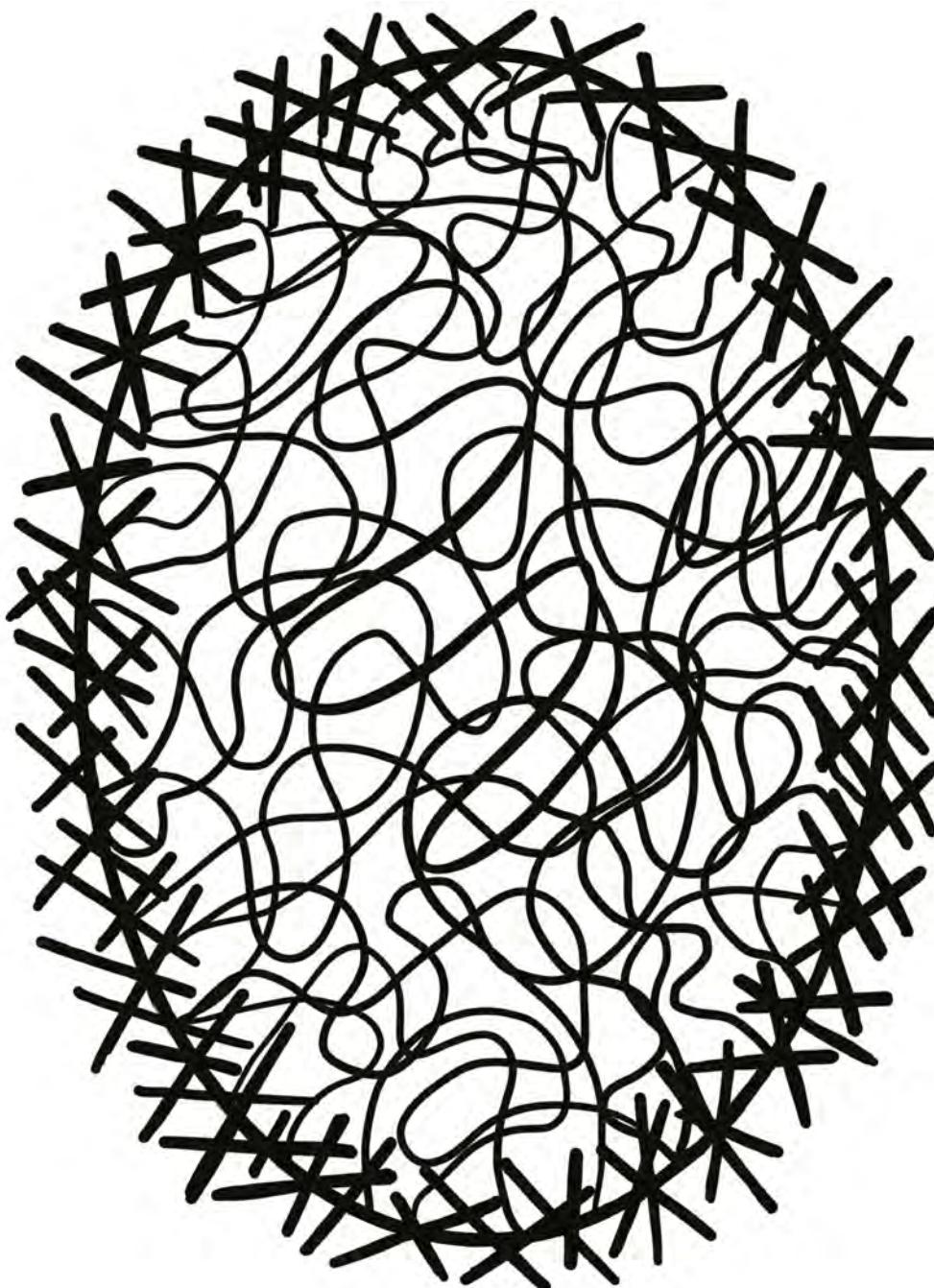
First, attach the tail to the top of the body. To do this we use a technique called spot welding. Hold your pen in one place where you want to attach the tail and allow some plastic to puddle. Before it has time to set, position, and press down the top of the tail. Hold down until the filament has set.

Now turn the body over and add some more plastic to securely join the two pieces together.

Next, attach the spine decoration to the body using the same spot welding techniques, and reinforcing on the underside. Then take your wings and position on the body and secure with spots of plastic. You need to hold them in place until completely set.

Then, carefully run a line of plastic along the inside and outside of the joins to strengthen them. Remember to hold the wing in position until both sides of the new joining plastic are set. Ensure there is a secure join and repeat if necessary.

You can use your dragon as a flat creature and attach to a box lid for decoration, or simply hand it around. But it is possible to give it a more 3D appearance. Open filled shapes can be gently bent. Try bending the feet outwards. If your plastic will not bend easily, simply run a line of new plastic along the thick line between the foot and the leg. The new hot plastic will heat and soften the other plastic around it. When it is cool enough to touch but not set, you will find it should bend easily. Do the same where the front legs join the body, and bend inwards. On the back legs make two bend points on the legs. You may need to keep bending and shaping to make your dragon stand. Gently bend the wings and the tail to add a little movement to them. Bend the gills upwards.



**DRAGON'S  
BASE**

### MAKE A BASE FOR YOUR DRAGON

Drawing circular and oval shapes can be quite difficult so here we use straight lines to form the outline. Once you have completed the outline use the filigree infill technique.

### JOINING THE DRAGON BODY TO THE BASE

Decide where to position your dragon. Initially we attach the legs to the base with the spot welding and reinforcing techniques. Twist and bend the tail and fix the end to the base in the same way. □

### EXTENSION IDEAS

Make your dragon in different colours. Add flames to the mouth and maybe spikes or horns to the head or body. Lighting brings a 3D pen sculpture to life. I usually use a variety of small, battery-powered, wired string LED lights. Add these to the back of the base, and then add a hanging ring and turn your 3D pen Dragon into a wall art light. You could probably use lights controlled by a Raspberry Pi!

**Above** □  
The base gives a solid foundation to your build

# No code needed: LED shoes

Make your feet sparkle



Sophy Wong

@sophywong

Sophy Wong is a designer, maker, and avid creator. Her projects range from period costumes to Arduino-driven wearable tech. She can be found on her YouTube channel and at [sophywong.com](http://sophywong.com)



**MG shoes!** Here's a simple project with a high-impact end result: LED shoes. Light-up shoes are everywhere these days, and you can definitely make your own.

You don't even need to know how to code or solder for this build. This a great first project for anyone who wants to get started with wearable electronics, and a fun, quick project for advanced makers.

We'll keep it simple and build a soft circuit – no soldering needed! You also won't need a sewing machine. Sewable components go together quickly

with conductive thread, and hand-sewing is a useful skill to hone. We'll use two universally valuable hand stitches in this project: a running stitch and a whip-stitch. You can make almost anything with these two stitches, and you won't regret having them in your skill set!

You can use this circuit and these components in any fabric project that you want to add light to. It's a perfect fit for cosplay, and would work well in gloves, hats, or any soft accessory. Always wear socks with these shoes, so that the sewn circuit does not touch your skin. It's also a good idea to coat your finished project with a hydrophobic spray



like Scotchgard. (You'll want to stay out of puddles and skip these on rainy days.)

The shoes used in this tutorial are canvas high-top trainers. High-tops don't just look cool, they also provide a lot of surface area to work with for decoration and spacing your circuit out comfortably. Canvas is easy to sew through, and sturdy enough to keep its shape while supporting the weight of the electronic components. Boots would give you even more surface area to work with, but be wary of leather shoes for this project: leather is harder to sew through and less forgiving than fabric, as piercing leather leaves permanent holes.

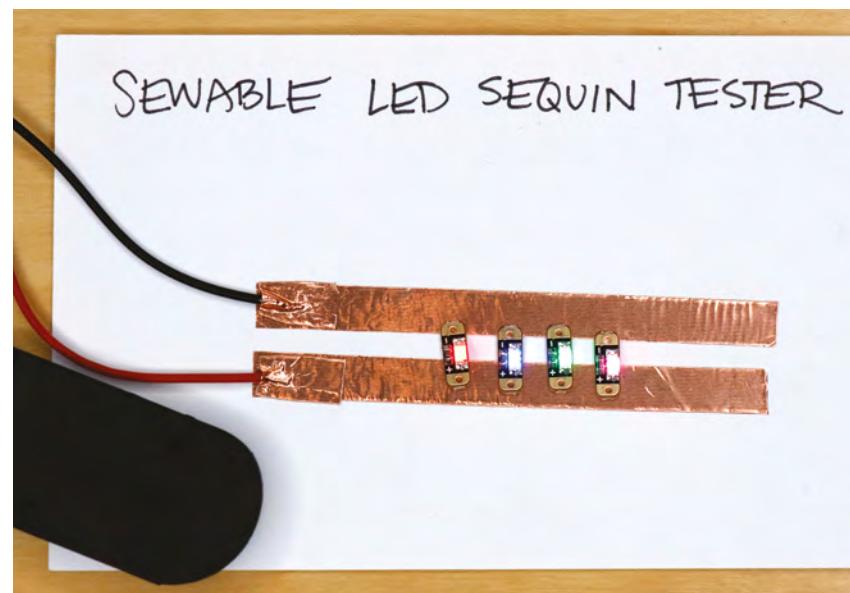
### ELEMENTARY ELECTRONICS

Tiny, sewable LEDs are perfect for wearable projects, and are easy to get started with. We used Adafruit LED sequins (\$3.95 for a pack of five) in our build, and Pimoroni sells Lilypad sewable LEDs (£3 for a pack of five) as well. These are not RGB LEDs (like NeoPixels), but single-colour LEDs that do not require a microcontroller to function. Just provide 3 to 6V DC and you've got light! Each LED has a resistor on board, so all that's needed is an appropriate power source, like a coin cell battery or two. We'll chain five of them together for a line of light on our shoes. When planning your design, you'll want to know what your LEDs look like when they are lit up, so we'll make a reusable tester card. Keep it in your toolkit for future projects!

Although the LEDs in this project are sewable components, we will use a battery holder that is not specifically made for sewing projects. We'll modify the battery holder slightly to work with our sewn circuit, and leave it accessible on the outside of each shoe for easy battery changing. Sewable battery components are available, too; just make sure to find one with an on/off switch.

#### **Below**

PCBs can have bumps where they separate from a panel. A quick sand down tidies things up



There are lots of ways to decorate plain trainers, from textile paint to sequins – have fun with this! White shoes make a good reflective surface for catching the light, while dark shoes would make the LEDs stand out like stars in the night sky. We kept it simple with a black marker on white shoes for a monochromatic look. When the LEDs are turned on, their colour reflects on the white canvas for a swirlly, bright effect in the dark!

### MAKE AN LED TESTER

If you've never used these sewable LEDs before, it can be helpful to make a tester card with some copper tape and the battery holder. Take an index card and two strips of thin copper tape about 8cm long. Apply the tape to the card about 5 mm apart. These will be the power rails of your tester card.

Strip about 1 cm of insulation from the ends of the battery holder's wires. Using more copper tape, attach each wire to one of the rails, as shown above. Press the tape down securely over the wires for solid contact. Add batteries to the battery holder and flip the switch to on.

Sewable LED sequins from Adafruit come in strips of five. Snap off each LED, and use an emery board to file down the rough edge that was attached to the strip.

Now you can lay your LEDs across the rails, with the positive pin (+) on the positive rail (the red wire), and the negative pin (-) on the negative rail (the black wire). The LED should light up solidly. If not, try wiggling the LED around or pressing down on it for a good connection. Use this card to view the colours of your LEDs and make sure they're all working properly before you sew them into your project. Hold onto this card for future projects! →

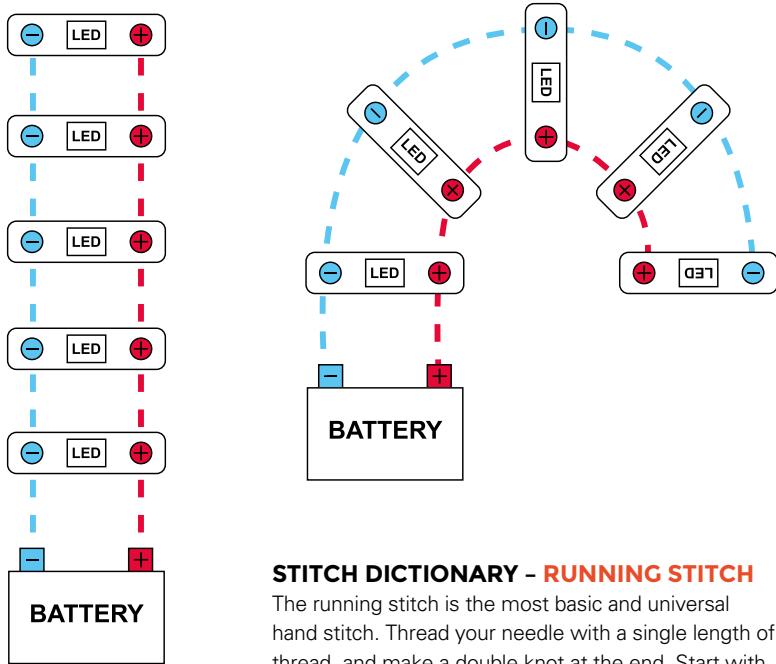
**Above** Double-checking LEDs before committing them to the project

### YOU'LL NEED

- ◆ **Canvas high-top trainers**
- ◆ **Sewable LED sequins** (Adafruit, five per shoe)
- ◆ **Battery holder with on/off switch** (one per shoe, plus one for tester)
- ◆ **2032 coin cell batteries** (two for each shoe, plus two for tester)
- ◆ **Conductive thread**
- ◆ **Erasable ink pen**
- ◆ **Markers or textile paint**
- ◆ **Index card or small piece of cardstock**
- ◆ **Copper tape**
- ◆ **E6000 or other strong fabric glue**

# No code needed: LED shoes

## TUTORIAL



### STITCH DICTIONARY - RUNNING STITCH

The running stitch is the most basic and universal hand stitch. Thread your needle with a single length of thread, and make a double knot at the end. Start with your needle on the back side of your fabric, and push your needle through to the front of your fabric so that the knot is hidden on the back of your work. Make small running stitches by piercing the fabric in equal amounts – about 2 or 3mm at a time – passing the needle under and over the fabric. Your stitching should look like a dashed line.

### STITCH DICTIONARY - WHIP-STITCH

The whip-stitch is useful any time you want to attach something long and skinny, like wire or cord, to fabric. It's used a lot in wearables, and is great for attaching wires! Start the same way you would with a running stitch: thread your needle and tie a knot at the end of your thread. Push the needle through the fabric from back to front, coming up on one side of the wire you

**Above** It's a simple circuit: just connect all the positives together

**Below** We'll use a regular battery holder for this project

want to attach. Take your first stitch by pushing the needle down into the fabric right next to the wire, then up through the fabric coming up on the other side of the wire. For the next stitch, pass the needle back over the wire and take another stitch underneath it, in the same direction as the first stitch. Continue down the length of your wire, sewing over it, making sure not to pierce the wire's insulation as you sew. Keep your stitches a few millimetres apart for a secure hold. When you reach the end, tie off your thread on the back of your work. This method is also called 'couching' in embroidery.

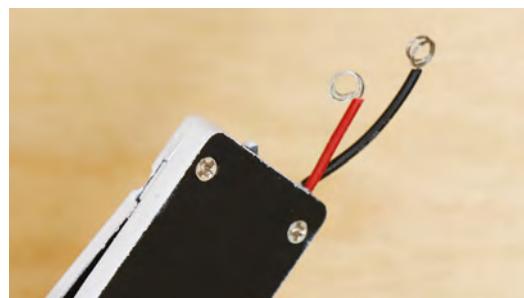
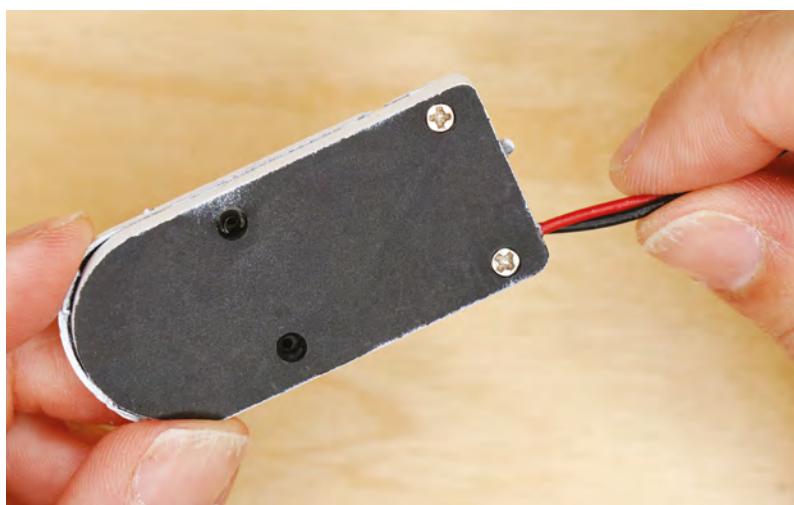
### DESIGN YOUR SHOES

Take some time to design your shoes and decide where your LEDs will go, and how you'll decorate the shoes. It's important to do this first, so you can plan out your circuit accordingly. These canvas trainers have prominent stitching near the lacing holes, so we built our design around that. Find a nice flat area to mount the battery holder to, making sure it won't catch on anything as you walk. The inside ankle area is a good choice. We like the holder on the outside of the shoe, but if it's comfortable for you, you can try putting it on the inside.

While working on your design, keep in mind that each LED has a positive pin (+) on one end, and a negative pin (-) on the other. To chain the LEDs together, you'll need to connect all the positive pins to each other, and all the negative pins to each other, without crossing any connection lines – negative and positive should never touch. Arranging the LEDs like a ladder keeps the pins properly aligned and ensures that power and ground will not touch. If you prefer to lay the LEDs end to end, sew the positive pins together on one side and the negative pins on the other.

When you're happy with your design, it's time to start making!

**Below** You can make many electrical components sewable with a loop in the wire





**Above** ♦  
The battery holder needs to be secure as it'll have to withstand quite a lot of shaking

### PREPARE THE BATTERY HOLDER

Our battery holder was black, and a quick hit of white spray paint made it blend in better with the white shoes. If painting your battery holder, cover the back of it with masking tape first so that it can be glued to the shoe later. To make our battery holder sewable, we used a tiny hand drill to make four small holes in the back of the holder.

When dry, cut the wires so that one wire is about 5 cm long, and the other is about 6 cm long. Staggering the wires helps ensure that the loops won't touch when they are sewn down near each other. Strip about 3 cm of insulation from each wire. Twist the exposed wires slightly, and then wrap them around something skinny and round (like a small screwdriver) to make tiny loops. These will be our connections for the conductive thread traces that



**Above** ♦  
We've opted for a gentle curve of LEDs, but you can go for any design you like

**Left** ♦  
Remember that your stitching will be visible, so plan your pattern

**“** **To make our battery holder sewable, we used a tiny hand drill to make four small holes in the back of the holder** **”**

will carry power to the LEDs. Optionally, if you have a soldering iron handy, adding solder to the loops makes them sturdier and easier to work with.

Position the battery holder and glue it in place with E6000, or other strong fabric glue. For a secure attachment, hand-sew the battery holder to the shoe using the holes we drilled. Use strong upholstery thread, or a double strand of hand-sewing thread for this step.

### ARRANGE THE LEDs

Refer to your design for the placement of the LEDs on your shoes. Arrange the LEDs on each shoe, making sure the power and ground pins are all

correctly aligned. Then, use a dab of fabric glue or E6000 to hold each LED in place.

Now that we have the battery holder and LEDs attached, we can draw out our connection lines so we know exactly where to sew. Using an erasable pen, start at the wire loops from the battery holder, and draw a line connecting the negative wire to all the negative pins on the LEDs. Then repeat for the positive wire and positive pins. Your lines should never cross each other, and stop at the last LED.

### SEW THE CIRCUIT

Thread your sewing needle with a long strand of conductive thread. Start by whip-stitching a few times around the negative wire loop from the battery holder, pulling your stitches tight for a good connection. Then use a running stitch to sew along your line to the negative pin on the first LED. Take four or five tight stitches through the negative pin to make a good connection and secure the LED to the shoe. Continue down your sketch line, until you've connected all the negative pins together. Ideally, →

## TUTORIAL



you'll sew the whole line in one go, so use a strand long enough to reach from the battery holder to the last LED in your chain. (If your thread runs out before you get to the end, no biggie! Just tie it off at one of the LEDs, then start a new strand in the same LED and continue.)

After sewing through the last LED, tie off the thread with a tight double knot. Dab a little CA glue or Fray Check on the knot for extra security. To bury the thread tail inside the fabric, take a stitch between the canvas and the lining of the shoe (the stitch shouldn't show on either the inside or outside), and pull slightly while cutting the thread flush. The thread tail will disappear safely into the fabric.

**Above** Keep your stiches through the LED tight to ensure a good connection

**Below** A careful final stitch will disappear into the shoe

If any LEDs flicker or don't light up, check that the pins are correct and that your stitches are tight

Repeat this process to connect the positive pins to the positive loop on the battery connector. When you've finished sewing your connections, pop two coin cell batteries into the battery holder and switch it on. Your LEDs should all light up solidly. If any LEDs flicker or don't light up, check that the pins are correct and that your stitches are tight. Also make sure that the power and ground lines are not touching at any point, and that you've cut any exposed thread tails short. When your LEDs are lighting up as intended, remove the batteries and set them aside.

### FINISHING TOUCHES

Now that we're sure everything works, we can put the finishing touches on our circuit. First, let's secure the battery loops to each shoe. Thread your sewing needle with regular sewing thread that is the same colour as your shoe, and whip-stitch all the way around the loop, so that the thread covers the exposed wires completely. This will keep the loop in place, as well as provide some strain relief and insulation. Tie off the thread, cut the thread tail short, and hit it with a bit of Fray Check for stability.



**Above** Make sure everything's securely attached before finishing up

Next, take a few stitches around the wires of the battery holder to keep them in place against the shoe and make them less likely to catch on things as you walk. That's all the hand-sewing needed for this project!

You're now ready to erase the sketch lines you made for your circuit, and the method will vary based on the type of marker you used. Many erasable pens for sewing require water for removal, but that's not ideal when working with electronics. The markers we used in our project disappear with heat, and a small craft iron makes quick work of erasing them.

### DECORATE YOUR SHOES

Now all that's left to do is to finish decorating your shoes so they don't just look good in the dark! Use whatever method you prefer to decorate your

shoes: fabric paint, markers, or glue and sequins. For a cleaner application, stuff your shoes with stiff paper to hold their shape while you work. Sketch your design on the shoes with an erasable pen or light pencil first, then go for it with your art supply of choice. Fabric markers can be heat-set with a craft iron. To make the battery holder blend in even more, make your design flow right over it. Alternatively, you can make it stand out by painting it with a bright pop of colour. The choice is yours!

When your creation is complete, coat your shoes with hydrophobic spray to keep your design clean and your electronics dry. Then insert your batteries, flip the switches, and light up your shoes! You can use this same technique to make other accessories light up. There are endless design possibilities and lots of ways to customise your LED wearables. Show us your shiny projects at [@HackSpaceMag!](#)

**Above** Finish your design off with a permanent marker for some custom shoes

**Below** Time to hit the streets and reap your newfound geek-cred



# Playing (tunes) with your food

Make a touch-sensitive cake that plays music



**Ben Everard**

@ben\_everard

Ben loves cooking stuff – his fridge is packed with a thousand highly experimental dishes which only he will end up eating...

**F**ood, music, and electronics are three of our favourite things, so it only makes sense to attempt to combine them all into one delicious, melodious circuit – surely? We decided to try to make a touch-sensitive cake, on which you could actually play different notes by touching different parts of it, like a kind of tasty edible piano. You can do this with more or less any controller that can take touch input (regular GPIO pins won't work; they have to be touch-sensitive). We tried this with an Adafruit Circuit Playground Express and a Bare Conductive Touch Board, and both worked without problems. But before we get to the controls, let's take a look at the tasty part of the build – the cake.

The main challenge of this build is that we want a single cake with multiple parts on it which respond to touch. Simply putting the electrodes in the cake doesn't work, because cakes aren't very conductive. To make this work, we need a way of getting a conductive electrode on the surface of the cake. We could just put an electrode on there – there are plenty of food-safe electrodes, such as aluminium foil – however, we want the entire cake to be edible, and this meant creating an edible electrode.

There are some conductive doughs that use salt and/or lemon juice; however, they stretch the definition of edible – they might not outright kill you, but they're going to taste horrible and, if eaten in quantity, might make you throw up. Not exactly





qualities we look for in a cake. That left one option: edible metal foil. Pure forms of silver and gold are both edible and – when hammered into fine foil – malleable enough for cake decoration. We believe both gold and silver foil should work, but we used silver leaf because we're cheap, and it's a better conductor anyway.

While both gold and silver are expensive metals, they can be beaten incredibly thin – often around 0.1 micron. To put this in perspective, you'd have to stack 750 of these sheets on top of each other to get the thickness of a human hair.

## Gold and silver leaf comes in a few forms – most commonly, loose leaves and transfer sheets

Gold and silver leaf comes in a few forms – most commonly, loose leaves and transfer sheets. In principle, both should work. We opted for transfer sheets, which are leaf metal on tissue paper. This allowed us to cut the leaf into strips the right width for our keys before applying.

### GILDING THE LILY

We bought a pack of 25 silver leaf transfer sheets for £9.85, and we used five in this cake, so the total silver cost was a measly £2.

Do be careful when buying edible leaf though, because there are many types of non-edible imitation and genuine, but less pure, silver and gold leaf around. Typically, these contain non-edible metals (such as copper), so always buy from a reputable source and ensure that it's marked as edible.

You can use a wide variety of cakes, but they do need to have firm – and ideally fondant – icing. Our



first attempt was on a cake with butter icing, but the leaf is so delicate that the slightest movement rips it apart and this softer icing couldn't support it well enough to create a continuous conductor. Fondant is firm enough to hold the leaf in place and just sticky enough to adhere to the leaf.

It's hard, but not impossible, to get the leaf to adhere around shapes and strange contours on the cake. The flatter the edges of the cake, the easier it will be to coat, so it's best to start with a simple design. We cheated and bought a supermarket cake – this isn't a baking tutorial after all. We'll leave it up to you whether or not to start from scratch.

With all that out of the way, let's get on to making the keyboard cake. First, you're going to need some electrical contacts for the cake to sit on. This is what you'll wire up to your touch-sensitive board. You need to start with a non-conductive base, such as a plate (note that many cakes come on foil bases that are slightly conductive). You'll need to move your cake off this onto something non-conductive before starting. →

### CAPACITIVE TOUCH

Capacitive touch essentially works by sensing the capacitance of a particular output. When you touch it, your finger affects the capacitance and this is detected and processed as a 'touch' that you can process in your code. This is different from general input/output pins that need a voltage applied in order to trigger an action. On some devices, I/O pins are both normal pins and capacitive touch sensors. You may need to set them up differently in your code. You'll often find that touch-sensitive inputs are larger conductive pads designed for crocodile clips rather than 'pin' headers. However, this isn't a universal thing.

**Left** Silver leaf transfer sheets enable you to shape the silver before applying it to the cake

**Above** The cake-to-plate transition is the trickiest part of the wiring, but did work after some practice

- ◆ **Cake**
- ◆ **Fondant icing**
- ◆ **Silver leaf**
- ◆ **Aluminium foil**
- ◆ **Touch-sensitive board**

# Playing (tunes) with your food

## TUTORIAL



### Above ♦

You might have to apply a few layers of leaf in order to get a continuous conductor

On this non-conductive base, you need some ‘pads’ that form the interface between your Touch Board and the silver leaf on the cake. Aluminium foil is the obvious choice, so start by cutting out sections of foil about 2cm by 5cm, and taping them in place on this base. They’ll need tape in the middle so that the cake is sitting on bare foil, and there’s also bare foil to attach a crocodile clip to on the opposite side of the tape to the cake – this is so the crocodile clip won’t move the foil and break the connection with the

### Right ♦

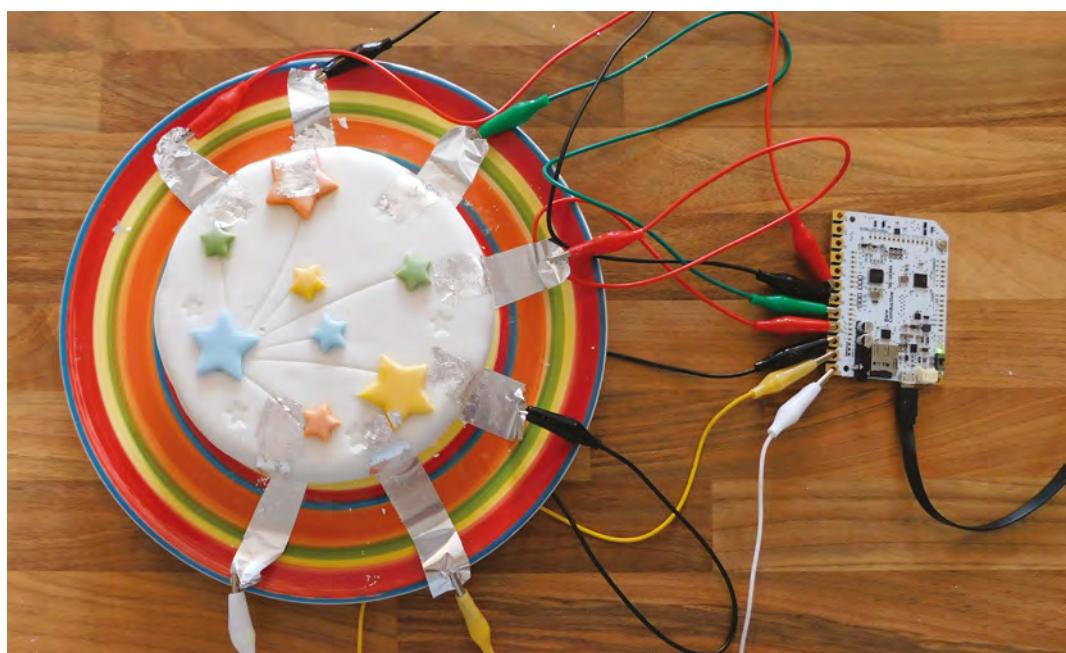
The wiring couldn’t be simpler. Just attach the foil to the touch-sensitive inputs with crocodile clips

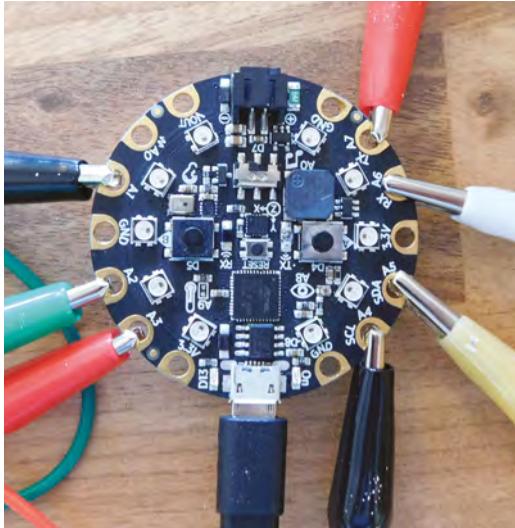
silver leaf. The number and placement of these pads is up to you. Take a moment to look at the cake and see how you want the ‘keys’ laid out, and then work backwards from this to where you want the pads. You’ll need at least 3cm between the pads to avoid any cross-talk. If you want to play *Happy Birthday*, for example, you’ll need at least seven notes, as it doesn’t use sharps or flats.

Once you’ve got these in place, pop your cake on top and it’s time to get gilding.

## MUSICAL DECORATIONS

You start with silver leaf on the transfer paper and you want to end up with it on the icing. The first part of this is making the icing a little stickier. Brush it lightly with water. You don’t want it to be wet, but just damp enough to be tacky. Then cut the transfer paper up into strips about 1–2 cm wide and 2–3 cm long (this will depend on the pattern you want on the cake, but this width worked well for us). It’s much easier to shape the leaf while it’s still on the paper than trying to apply a whole leaf but with only some sticking. You should then be able to lay your transfer paper down on the damp icing, rub the back of the paper (scratching can help too), and peel it back, leaving the silver leaf on the icing. You’ll often find that you get some leaf that’s come off the transfer paper but hasn’t properly stuck to the icing. It’s handy to have a clean brush to push it onto the icing with (but if you don’t have one, a clean finger will usually do the job).





## THE EASY WAY

There are many, many ways this project could be done far more easily. A large amount of the problem is the fact that we're converting a single object into a completely edible multi-touch interface. If you're willing to drop either the single object or the entirely edible, then the whole thing becomes much simpler.

Fruit is conductive enough for capacitive touch and you can wire up different fruit to a capacitive touch interface by simply sticking an electrode in them. Get seven fruits and seven electrodes and you can create the same musical interface as our cake, with no gilding required. Alternatively, if you're willing to include non-edible items on your cake, then everything becomes simple. Perhaps some foil-covered chocolate coins could be connected to the touch inputs, or simply aluminium foil cut into an interesting pattern.

That, at least, is the theory. It's a bit tricky in practice because the leaf is so delicate, and can at times seem to refuse to stick to the icing for no discernible reason. You'll almost certainly find that you don't get a continuous trace from this, so you'll have to go back over some areas that you've applied leaf to and double or triple-up the leaf. This is to be expected, and using this, you can make traces longer than a single strip of transfer paper.

The hardest part of the endeavour is getting a contact between the silver leaf and the aluminium foil 'pads'. The most reliable way we found of doing this was to slightly crinkle the transfer paper before applying this section: that helps it almost fall off the transfer paper once it's pressed in, and then a gentle brushing (or prodding) will get it in place. Bear in mind that this connection will be very fragile, so if you plan on moving the cake more than a short walk, it might be best to do this after you've moved it.

### TOUCHY FEELY

The last part is just to wire the cake up to the touch sensor. This is just a case of clipping an alligator lead to the aluminium foil and attaching the other end to the touch pad on your chosen board.

When it comes to software, there's absolutely no point in writing your own unless you want something specific. There's almost certainly some pre-existing music setup for your board. If you've gone with the CPX, the Adafruit Lime Piano code works and can be found at [hsmag.cc/HMkREe](http://hsmag.cc/HMkREe), while if you've gone with the Bare Conductive Touch Board, you should find a MIDI example in your Arduino Sketchbook if you follow the installer here: [hsmag.cc/RsFoyH](http://hsmag.cc/RsFoyH).

### Left ↗

The internal speaker on the CPX isn't very powerful, but you could attach it to an external speaker between A0 and ground

If you've used MIDI code you're also going to need MIDI software on your computer to turn these signals into sound. We used ArcTrax, which is available in the Windows store, but any software that can take MIDI input should work. Just make sure your Bare Conductive Touch Board is connected, and select this board as 'MIDI in', and then you should start to hear melodic sounds when you touch your edible, electric cake. You should find similar software for other touch-sensitive boards too.

That's all there is to it, so what are you waiting for? Life's a bit nicer with cake, and even better with electrical cake, and the music is waiting for you – so don your apron and get baking. □

### Below ↘

All together now...  
Ha-py birth-day  
tooooo yooooo



# Pocket hole joinery

Make strong, accurate joints in wood, quickly and with no fuss



**Alex Eames**

@raspiti

Alex Eames loves making things and regularly blogs/vlogs about this at RasPi. TV He makes a living designing and selling RasP.iO products.

If you want to just make something quickly, and you're not fussed about spending hours crafting traditional joints (e.g. mortice and tenon, dovetail etc.), pocket hole joinery may well be for you. It lets you make strong, accurate joints that can easily be disassembled.

Occasionally you'll see someone online 'dissing' the technique as 'cheating'. And, in some ways, they're correct. It does enable someone to make something quickly and easily without becoming an apprentice joiner. But that's a good thing, right?

It's also used in flat-pack furniture, where ease of assembly and disassembly is vital. So, if it's good enough for IKEA, it's good enough for us makers.

Pocket hole joinery lets you make things really quickly and you can take them apart again. Mortice and tenon joints take ages and are permanent.

## SO WHAT'S A POCKET HOLE?

A pocket hole is a hole drilled at an acute angle (~15°), positioned so that a screw can pass through the side of the wood, out through the end, and into whatever it's being attached to. The hole is



counterbored, so that the screw can be completely recessed. The recess is usually located on the inner side of the construction so as not to be visible. You can also make or buy plugs to fill the recesses if desired.

## QUICK TIP

Before investing in a pocket hole joinery 'system', check out the cost of the proprietary screws and/or consumables.

**Top Right** Looking into the holes shows deeply recessed, square drive, pocket hole screws. Holes can be plugged and the plugs sanded flush, if needed

**Right** The Kreg R3 pocket hole jig kit is a well thought-out system. All you have to do is measure your timber thickness and 'join by numbers'



**Far Left**

The Kreg case is used to set the depth stop on the drill bit. The jig has calibration sliders set to match the wood thickness

**Left**

The Kreg screws have a square drive which requires a special driver bit (included in Kreg kits). Overall, the system works really well

**Below**

This laser cutter trolley uses cheap studding timber and pocket hole joints with 2.5 inch screws

**YOU'LL NEED**

- ◆ **Pocket hole jig**
- ◆ **Pocket hole drill bit**
- ◆ **Pocket hole screws**
- ◆ **Wood**
- ◆ **Saw**
- ◆ **Drill/driver**
- ◆ **Clamp**

To sidestep the time spent learning traditional methods, you usually have to buy a tool or kit and, in this case, it's well worth it. Drilling a counterbored hole accurately at 15° into a piece of wood isn't easy without a little help. If you Google 'pocket hole joinery', you'll see a vast array of jigs and fixtures on offer, from around £5 to £200. The cheapest ones are simply an angled drill guide which you clamp to your wood. More sophisticated sets include a stepped drill bit, and adjustable depth collar. This enables you to drill both the pilot hole for the screw, and the counterbore in a single action.

The better kits have hardened steel guides and offer a complete 'system', enabling you to position your holes precisely with no messing about. Some systems have their own proprietary screws and screwdriver bit as well. The system used here is the Kreg R3, which is their simplest jig and costs around £30.

**LET'S MAKE A JOINT**

Measure the wood thickness and select appropriate length screws. The Kreg R3 jig comes with a data table that makes this simple.

Position your drill guide so that the tip of the screws will exit the end of the wood as close to the centre as possible. You can do this visually or use the system provided with your jig. In this case, the Kreg kit has calibrated sliders on the jig that mark the required position relative to the end for various wood thicknesses.

Clamp the drill guide in place. Set the depth stop on the drill bit so that it matches the wood thickness and length of your screws. If you go too far, either the counterbore will be too deep (causing a weak joint) or

the screw will be too long. The Kreg system makes clever use of the case to help you set the depth stop correctly.

Drill your hole(s) to the correct depth.

To complete the joint, position the pieces of wood as you want to join them, then clamp them together. Then drive pocket hole screws through the pocket hole and into the target timber. If all went well, you should now have a strong 'disassemblable' joint. You should now be able to make structurally strong 'undoable' joints quickly and cheaply. Happy making! □

**QUICK TIP**

To get strong, close-fitting joints, the ends of your wood need to be as perpendicular as you can make them.

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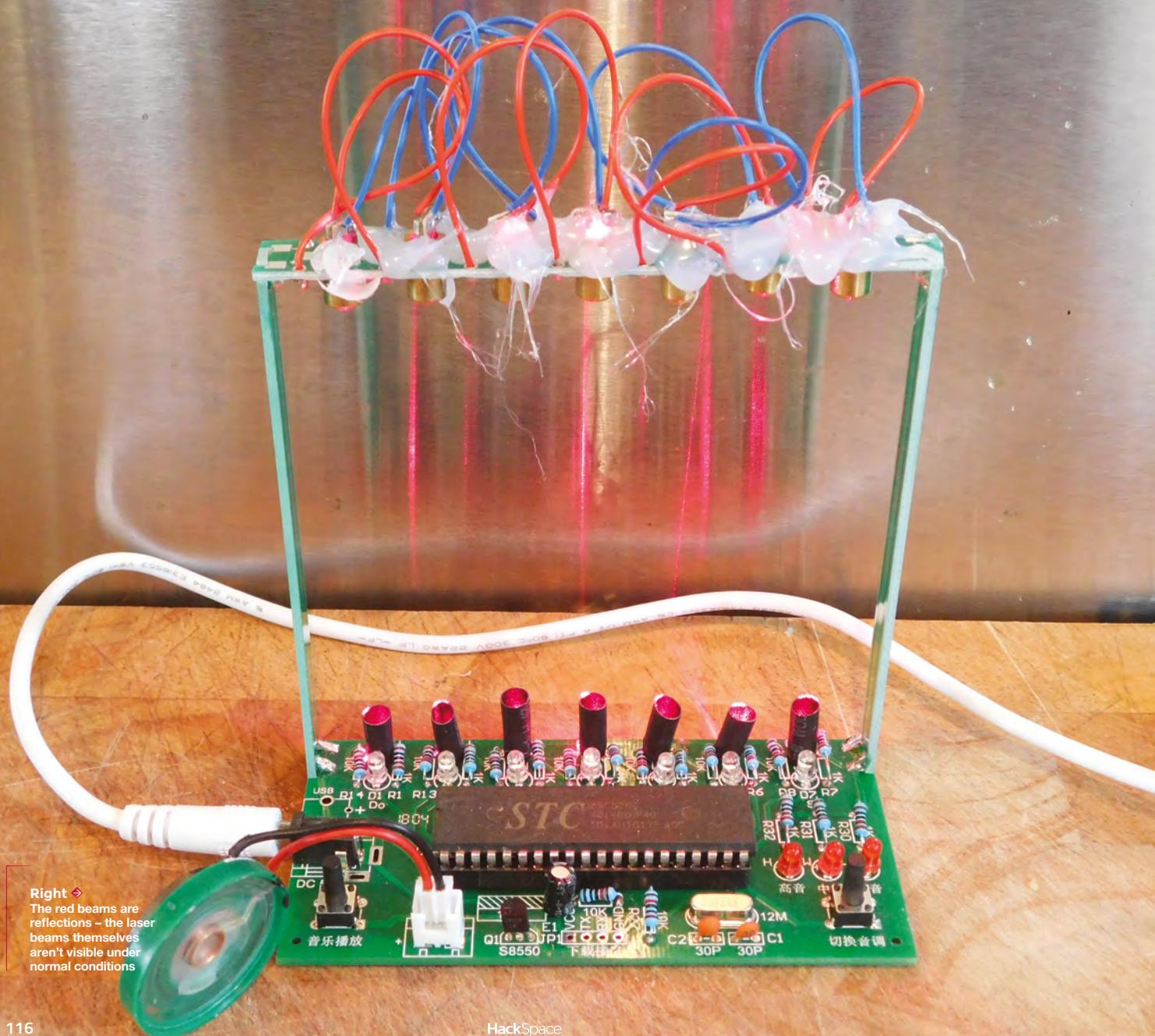
DIRECT FROM  
**SHENZHEN**

# Laser harp

Play tunes with a flick of your finger (no sharks required)

By Ben Everard

@ben\_everard



Right ↗

The red beams are reflections – the laser beams themselves aren't visible under normal conditions

**T**he basic principle of a laser harp is simple. It's a series of laser beams that, when broken, play a note. They vary from small hobby kits to huge performance instruments designed for stadium gigs. We purchased a small harp kit for £8.59 (including postage) from e\_goto Processors Store, on AliExpress. This is a 'framed' style of laser harp, where the laser beams shine onto sensors. Some other laser harps are 'frameless', where the lasers shine out to the distance. Frameless ones are more complex, but can work better at larger scales, particularly for performances.

The instructions came in Chinese, but they're not really needed. The PCB is marked with what component goes in which hole (everything's through-hole). The only slight issue was the orientation of the LEDs, as it wasn't clear which hole the plus sign in the silk screen referred to. Under close examination, we decided it was slightly closer to one hole than the other, and this proved correct.

The kit works by having a series of seven light-dependent resistors (LDRs) lined up on the bottom circuit board. These have a couple of centimetres of black plastic tubing slipped over them to block out most of the light. There are seven laser diodes, each lined up with an LDR, so that the beam fires straight down the tubing. When a laser beam is blocked, the light stops falling on the LDR and this triggers the harp to play a note.

### POWER TRIP

When working with lasers, it's always sensible to consider the potential dangers. The laser harp came with 5mW laser diodes – brighter than we were expecting – and the dots they create can be dazzling, even when hitting a non-reflective surface. The UK Government advice on this laser power (Class 3R) is: "The laser beams from these products exceed the MPE (maximum permissible exposure) for accidental viewing and can potentially cause eye injuries, but practically, the risk of injury in most cases is relatively low for short and unintentional exposure."

This kit is right at the highest end of laser power that's considered an acceptable risk for general use, and you should consider this before purchasing.

The laser diodes have to be aligned by hand, and secured in place with hot glue. This isn't the best-looking system (and be careful not to burn your fingers as you do it), but it does work. The tubing around the LDRs means that they don't have to be perfectly accurate – as long as they're within the circle of tube, they should work. If you're concerned



about aesthetics, you might want to enclose the top part of the harp in a more pleasing-looking material. Alternatively, you could easily create your own upper section – there's no need to use the PCB provided. The only wiring on this is to provide the laser diodes with power, so fitting this into wood or a 3D-printed structure should be fairly straightforward. However, if you do choose to modify the frame, you should consider whether this makes accidental exposure to the beams any more likely.

### BRAINZ

The board is based on an STC89C52 microcontroller. It's programmable, so in theory you could update this to behave in any way you want. However, this isn't a chip with much of a hobbyist community around it, so we wouldn't recommend trying to reprogram it unless you've got experience with truculent microcontrollers. A far easier way of modifying this project (should you wish to) would be to take connections from the input pins on the STC to another board, such as an Arduino Uno (the STC is a 5V part, so you'll need appropriate protection if you use a 3V microcontroller instead).

The biggest disappointment with this kit is that it's only able to play one note at a time, so the classic harp sound of running your fingers across the strings is impossible to recreate unless you're willing to modify the software. However, if you're careful, it can be used to play a short tune. The harp creates a square wave which has a very computer-y bleep sound that's perhaps most commonly associated with chiptune-style music. There is a certain charm to this sound, but it's not very reminiscent of a harp. Close your eyes, wave your hand around in the harp, and the noises will take you back to the halcyon days of 1980s gaming.

This is a fun kit to put together, and makes an unusual curiosity. If you're willing to go further, it offers some possibilities for hacking into more visually pleasing forms. However, unless you're willing to tinker about with the microcontroller, you're not going to get anything capable of making interesting music. □

**Above** Plastic sleeves block out other light from the LDRs

DIRECT FROM SHENZHEN

BEST OF BREED

ONLY THE  
BEST

# Radio communications made easy with Bluetooth

Bluetooth is everywhere, but how do you add it to your next project?

By Marc de Vinck

 @devinck

**B**luetooth. We've all heard of it, and we've all used it at some point. You most likely were introduced to Bluetooth when you connected your phone to your car, or when listening to music on wireless headphones. It's a fairly ubiquitous technology that isn't all that old. According to Wikipedia, it was invented in 1994, by a Dutch electrical engineer named Jaap Haartsen, as an alternative to the RS-232 data cable. Ultimately, several engineers were involved in developing the final implementation and integration of the technology, which allows the exchanging of data wirelessly via radio waves in the 2.400–2.4835GHz ISM band. Sound complicated? It can be, but implementing and leveraging this technology in your next project doesn't have to be difficult.

Early Bluetooth technology was interesting, but not always reliable, and not particularly easy to implement. As the technology advanced, and the new Bluetooth Low Energy (BLE) was introduced, it became more popular and easier to implement. In addition to the lower power consumption of BLE, it has greater range which, under ideal conditions can theoretically be over 300 feet, but in practice is typically much less. It also features less latency and, most of all, uses as little as 0.01W compared to 1W of classic Bluetooth. Of course, that all depends on how you use it in your specific project.

There are a lot of options out there for implementing Bluetooth in your next project. In this Best of Breed, we'll be looking at a few different boards, components, and shields that you can use in your next build, all of which integrate Bluetooth in



one way or another. In the future we will definitely be seeing more microcontrollers and single-board computers that will integrate Bluetooth into the board itself, eliminating the need for any additional hardware. Already, so many boards feature WiFi and Bluetooth, and for very little extra cost. Just look at the Raspberry Pi Zero W as a perfect example: it's extremely inexpensive, and it integrates 802.11 b/g/n wireless LAN along with Bluetooth Low Energy (BLE).

Above  Some boards have integrated Bluetooth, like the Raspberry Pi 3 and Pi Zero W

# SparkFun Bluetooth Modem vs Adafruit Bluefruit LE UART Friend

A serial connection through the airwaves

**SPARKFUN** \$24.95 | [sparkfun.com](http://sparkfun.com)

**ADAFRUIT** \$17.50 | [adafruit.com](http://adafruit.com)

**D**on't be intimidated when you want to add Bluetooth to your project. By selecting the right breakout board, it can be as easy as attaching a few wires and uploading some code. The SparkFun BlueSMiRF Silver Bluetooth Modem is a good example of how easy it is to implement into almost any project.

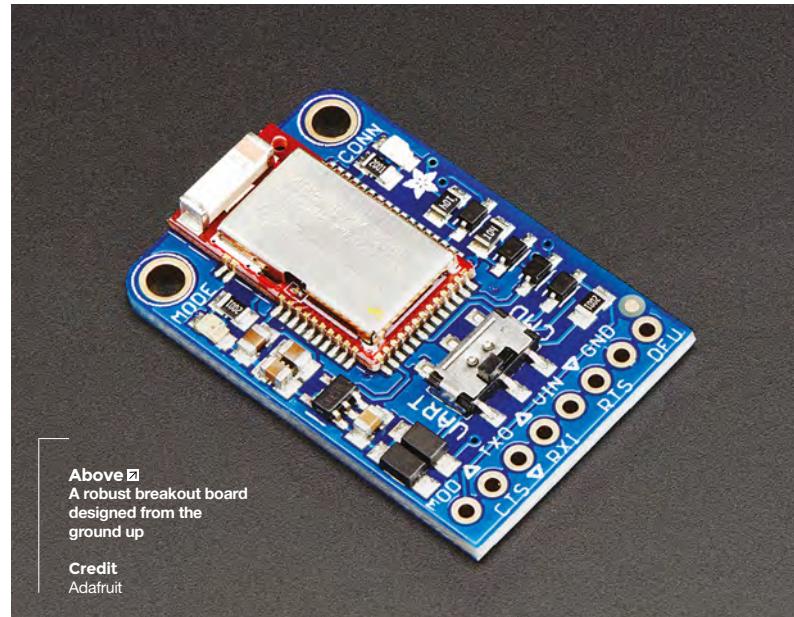
The SparkFun BlueSMiRF Silver is a serial cable replacement breakout board that uses the RN-42 module, which has a bit less range than the BlueSMiRF Gold version that uses the RN-41 module, but it's also a little less expensive. The BlueSMiRF Silver works as a serial transmitter and receiver working at a baud rate from 2400 to 115200bps, which makes it really useful for transmitting data wirelessly at a range of about 50 feet, depending on the specific environment.

In addition to the low cost of the BlueSMiRF Silver, Sparkfun has created a comprehensive hookup guide that covers all of its Bluetooth breakout boards, and it even has a primer on the underlying radio technology of Bluetooth itself, which we found very helpful.



Credit  
Sparkfun Electronics

**Above** Small and simple make this a good choice for adding Bluetooth to your next project



**Above** A robust breakout board designed from the ground up

Credit  
Adafruit

If you are interested in adding Bluetooth Low Energy to your next project, it's hard to go wrong when selecting the Adafruit Bluefruit LE UART Friend. This board makes implementing wireless data transmission between your smartphone and an Arduino fairly easy. But you aren't limited to just communicating with your phone: you can also make it act like a HID keyboard or create a UriBeacon. The Adafruit website has several well-documented examples, including how you can use the Bluefruit LE Python library to connect it to your Raspberry Pi.

There are definitely a lot of Bluetooth module manufacturers out there, but few can claim they wrote all the firmware for running the boards from scratch. Since everything is custom-designed from the hardware to the firmware, Adafruit was able to release a very robust breakout board that will stand the test of time. Adafruit has a few other variations of its Bluefruit breakout boards – check out the website for more details.

## VERDICT

Adafruit Bluefruit LE UART Friend

Great price and documentation make this board tough to beat!

**10**/10

SparkFun Bluetooth Modem

A great board to add to your prototyping supplies.

**9**/10

BEST OF BREED

## 1Sheeld+ for iOS and Android

Lots of options in just one shield

1SHEELD ◇ \$29.94 | [1sheeld.com](http://1sheeld.com)

The 1Sheeld+ is a powerful shield for Arduino that enables you to leverage the advanced features of your smartphone, like its high-resolution colour display, GPS, WiFi, accelerometer, gyroscope, and more, into your Arduino project. It's like buying a bunch of advanced components for your project, but you really only need one shield. Now the name makes a lot of sense.

The 1Sheeld+ also has another component: its app and the included virtual shields. You run the app on your iOS device or Android phone and it connects to your Arduino via Bluetooth. Now you can use the shield for a variety of different input or output scenarios. There are lots of virtual shields in the app, like a game



Left ◇  
Connecting to iOS or Android made simple

Credit  
Integreight, Inc.

pad, data logger, text-to-speech, barcode scanner, and more. This allows for very fast prototyping, and you don't even need to be an advanced programmer to get started. It's basically plug-and-play. At the time of writing this article, there were about 47 apps in total, each with a nice tutorial and documentation. That is a lot of functionality and power packed into the 1Sheeld. □

**VERDICT**  
A bargain price for a powerful shield.

**10/10**

## BLE (dual) Bee v1.0

A viking in insect's clothing

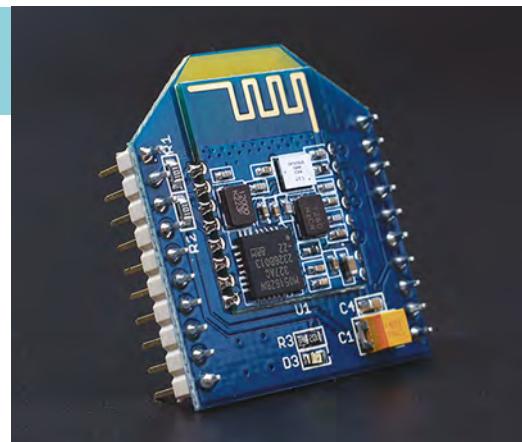
SEEEDSTUDIO ◇ \$19.50 | [seeedstudio.com](http://seeedstudio.com)

The BLE Bee v1.0 uses a dual mode Bluetooth chip, coupled with ARM architecture which supports AT instructions. There are several different scenarios where you can use this Bluetooth device in your project, making it fairly useful, especially if you already use the XBee form factor.

The BLE Bee can be programmed directly via a PC using AT commands, allowing your computer to connect to another BT device. You can add it to your Arduino project using one of the many different shields that support the XBee form factor. This

Right ◇  
A nice plug-and-play device that fits into a standard XBee formfactor

Credit  
Seeed Technology Co.,LTD.



would allow two Arduinos to talk with each other, or potentially another Bluetooth device. You can also pair it to your iPhone or any device that uses Bluetooth Enhanced Data Rate (EDR), or Bluetooth Low Energy. The website has an online wiki with lots of examples and information on all the different applications you can use. □

**VERDICT**  
If you're already using the XBee form factor, this board is for you!

**8/10**

# Annikken Andee U

An Arduino upgrade

**ANNIKKEN** ◇ \$59 | [annikken.com](http://annikken.com)

**A**nnikken Andee U is a Bluetooth shield for Arduino that allows the user to easily connect their smartphone to their microcontroller. It works with both iOS and Android, and doesn't require the user to have advanced coding skills. If you have a basic knowledge of the Arduino ecosystem, you can get up and running in no time.

Once you plug in the shield and download the software, you are ready to create your own widget. The Arduino code includes a variety of examples including creating a data box, button, keyboard input, gauge display, and more. Besides all these



**Left** ◇  
Connecting to your iOS or Android device is easy with the Andee U

useful features, you can also use the smartphone's sensors and hardware like the camera, text to speech capabilities, gyroscope, and accelerometer, or GPS data. We were able to get up and running fast, and really enjoyed the customisability of the included software. □

**VERDICT**  
A great board  
that's very easy  
to use and well  
documented.

**8/10**

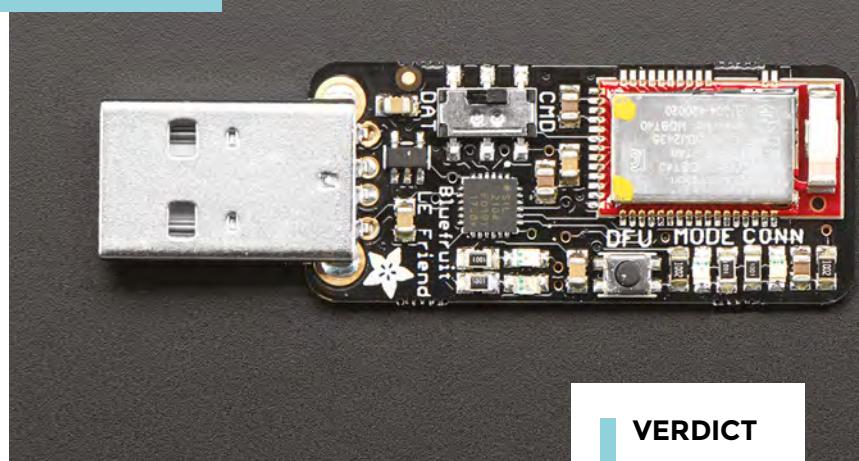
# Bluefruit LE Sniffer

Listen in to other hardware

**ADAFRUIT** ◇ \$24.95 | [adafruit.com](http://adafruit.com)

**T**he Adafruit Bluefruit LE Sniffer is a plug-in USB device that, once coupled with Wireshark – a popular open-source Bluetooth-sniffing program – will allow the user to read the Bluetooth Low Energy

**data being transmitted.** You'll be able to visualise things at a packet level, and with descriptors, which will save you a lot of time by not having to always reference a long datasheet or book of specifications. The website has a lot of useful information, including an example of how to reverse-engineer a Bluetooth Low Energy light, which are really helpful for getting started. □



**Above** ◇  
A plug-and-play way to  
'sniff' Bluetooth LE

**Credit**  
Adafruit

**VERDICT**  
A great way  
to learn  
more about  
Bluetooth LE.

**8/10**

CAN I HACK IT? ■

# Can I Hack It? An HDMI screen?

Can a small HDMI screen be used in your next project?



Les Pounder

@biglesp

Les Pounder loves taking things to pieces and seeing how they work. He teaches others as part of the Raspberry Pi Foundation's Picademy event. He blogs over at [biglesp.com](http://biglesp.com)

## YOU'LL NEED

GeeekPi 7-inch 1024×600 HDMI screen

## COST

£47

## WHERE

[hsmag.cc/oRNdeu](http://hsmag.cc/oRNdeu)



**L**CD screens are everywhere, in our watches, phones, living rooms, laptops... you get the idea. But, for this month's 'Can I Hack It?' we look at an LCD screen kit that offers us the chance to

make our own multimedia player, second screen for a laptop, or even use as part of a miniature arcade cabinet. So, let's take a look!

## GENERAL CONSTRUCTION

The HDMI screen measures 165×100×5 mm thick, and it is fragile, so be careful! There are no mounting holes, so careful consideration is needed to mount the screen securely and safely. A laser-cut frame would be great, and not too difficult to make. The screen connects to the main control board via a flat flex cable. The main control board also connects to a breakout board with screen controls.

## POWER

The unit is powered by a 12V 1–2A supply (not included), and the DC barrel jack should be centre positive, outer GND. Power can also be provided by a breakout connector just above the DC barrel jack connector. This gives us a rough power consumption of 12–24W, especially when using the included speakers. In the box there is a USB to DC barrel

jack lead, and this got us thinking, 'Could we power the screen from 5V?' We tested the USB to barrel jack lead using a 5V 2.5A supply, via a UNI-T USB tester and saw that, without the speakers in use, the screen needed 5V at 0.6A (3W), and when using the speakers at half the maximum volume, we used 5V at 0.8A (4W). However, when the screen and audio are used together with a 5V supply, the screen flickers to the beat of the music. So, if employing it as a screen for an arcade cabinet, we'd advise you to use a dedicated 12V supply!

## ELECTRONICS

The HDMI screen has a resolution of 1024 × 600 pixels, and connects to the main control board via a flat flex cable to the TTL port. The latter is rather fragile and uses a plastic locking retainer to hold the cable in place. There is also an LVDS connector for use with screens such as those found in laptops, but compatibility is not guaranteed. Once the screen is

**Above** The screen connects via a TTL flat flex cable, and is locked in place to the control board. Naturally, the cable flexes to enable the board to be 'carefully' affixed to the screen

connected to the main control board, we have a fragile and short connection. The natural place to store the control board is on the back of the screen, but on the reverse of the board we have many exposed contacts in the circuit, especially the power input. For best and safe results, affix the control board to the screen using self-adhesive plastic standoffs, commonly used in computer cases. If not, then use non-conductive double-sided tape; just make sure there is clearance between the board and the back of the screen.

The breakout board has controls for the power, volume, and on-screen display menu. All of these are push-buttons that can be desoldered and replaced with larger arcade-style buttons or other inputs. All buttons are connected to a single ground pin on the breakout board, so the GPIO pins they're connected to are pulled high and, when pressed, go low. This means we can easily hack the inputs with an Arduino or another 5V-compatible microcontroller, so gesture controls and adapting the inputs for those with disabilities is easy.

Audio is handled via two speakers attached to the main control board via a four-pin JST connector. This is connected to an APA2068 stereo 2.6W amplifier, enabling decent audio playback if used with an HDMI source. Looking at the pinout of the APA2068, we can see pins 9 and 11 used for the left speaker, and 14 and 16 used for the right, so we could bypass the connector if needed.

## CONNECTIONS

The main control board has lots of connections. An HDMI port supports audio input. VGA and composite

## SCREEN CHOICE

There is obviously more than one type of screen. In this case, we had a screen with its own control board offering VGA/HDMI and composite inputs. But for around the same money, we can pick up screens from Adafruit. For example, Adafruit has a 5-inch 800 × 480 HDMI touchscreen suitable for use with the Raspberry Pi. It may not be the biggest screen, but for simple retro gaming and media consumption it works well. The caveat is that there is no audio support for the HDMI, so we need to use an external audio amplifier – or if using a Pi, route the audio to the 3.5 mm jack.

Units such as the one we looked at can also be found in various sizes and configurations. A quick glance of AliExpress shows a \$9.99 10.1-inch version running at 1280 × 800 resolution via a RealTek RTD2660H HDMI driver chip (as used by Adafruit boards). The downside of this larger screen and resolution is that any LCD panel using the TTL connection will notice a loss of quality, so dropping the resolution to 1024 × 600 would be advisable for media applications.



ports offer a degree of flexibility for most users. There are also connectors for backlight and composite in, which can be used to breakout the connections and possibly provide an audio input for those using VGA.

## CAN I CONNECT IT TO A RASPBERRY PI?

The short answer is yes, but you'll need to edit your `boot/config.txt` file so that it detects and sets the correct resolution. Details are supplied in the box.

## CONCLUSION

This is a fragile, yet capable screen. Sure, the colour reproduction is a little cold, but we can change that in the menu. Sound is acceptable for general use, but for £47 we have a screen and audio that'll connect directly to our Pi / laptop / DVD/Blu-ray player with minimal hassle. The ability to power from 5V is handy for portable solutions (you may need a second screen when travelling for work) but this will mean no audio via this board.

The best use case for this screen is for a miniature arcade cabinet (using 12V supply), as it means that we can use a Raspberry Pi or other computer with HDMI output without the need for a separate audio board.

This is a fun board and it is ripe for hacking your next multimedia project! □

**Above** Connecting everything we need to the board involves a lot of wires, but we have a single solution for multimedia projects using many different computers or media players

**Below** The main control board has all of the ports needed to connect our screen, HDMI/VGA input, power, audio out, and a breakout connection for menu control



# PowerUp DART and X FPV

Add phone-controlled electric motors to your paper planes

**POWERUP** ♦ From \$39 | [poweruptoys.com](http://poweruptoys.com)

By Ben Everard

 [ben\\_everard](#)

**P**owerUp sell a range of modules for converting paper planes into radio-controlled flying machines, including the Dart and the X FPV. We first tried out the simpler of the two, the Dart.

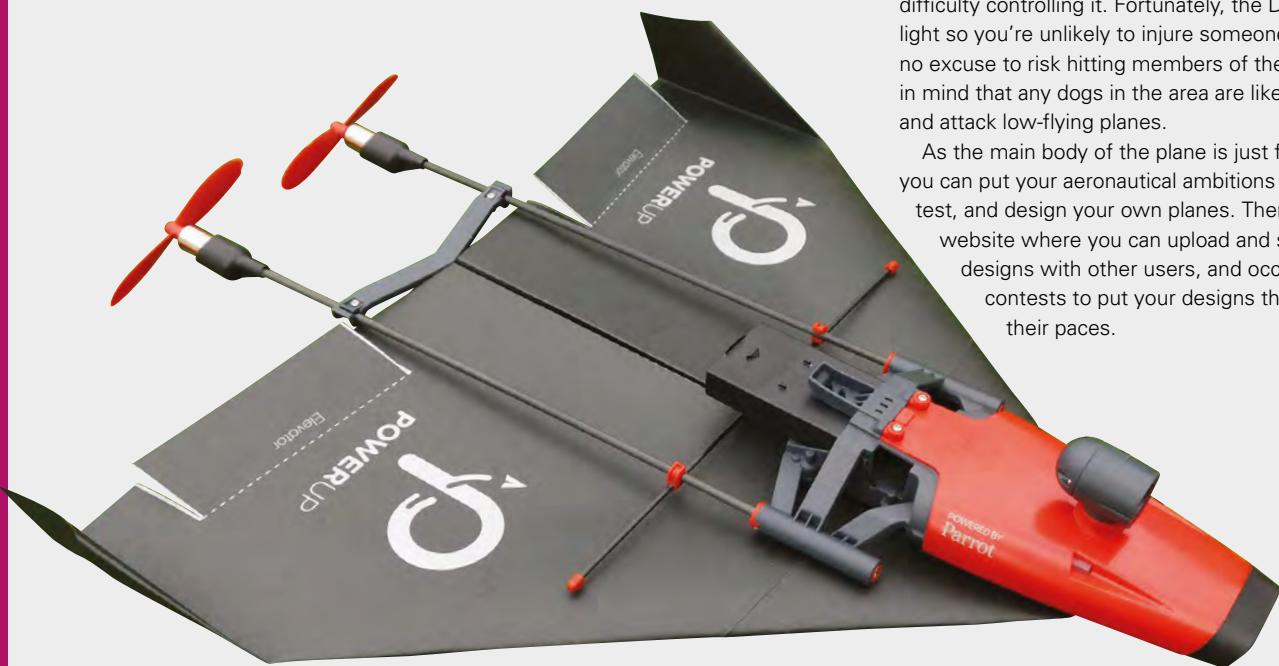
You get a module attached to a rod, with a motor and propeller on the other end. This way, the electronics and small LiPo battery are mounted on the front of the aircraft, while the propeller and motor are on the back – a configuration that balances the weight and protects the delicate rotor if (when) you crash. You also get a set of wheels, a rod to stiffen the plane, and a spare rotor. As well as the plane hardware, you get an instruction pamphlet, and four A5 printouts for paper planes (all the same model). Charge the plane, fold the paper, and you're ready to fly.

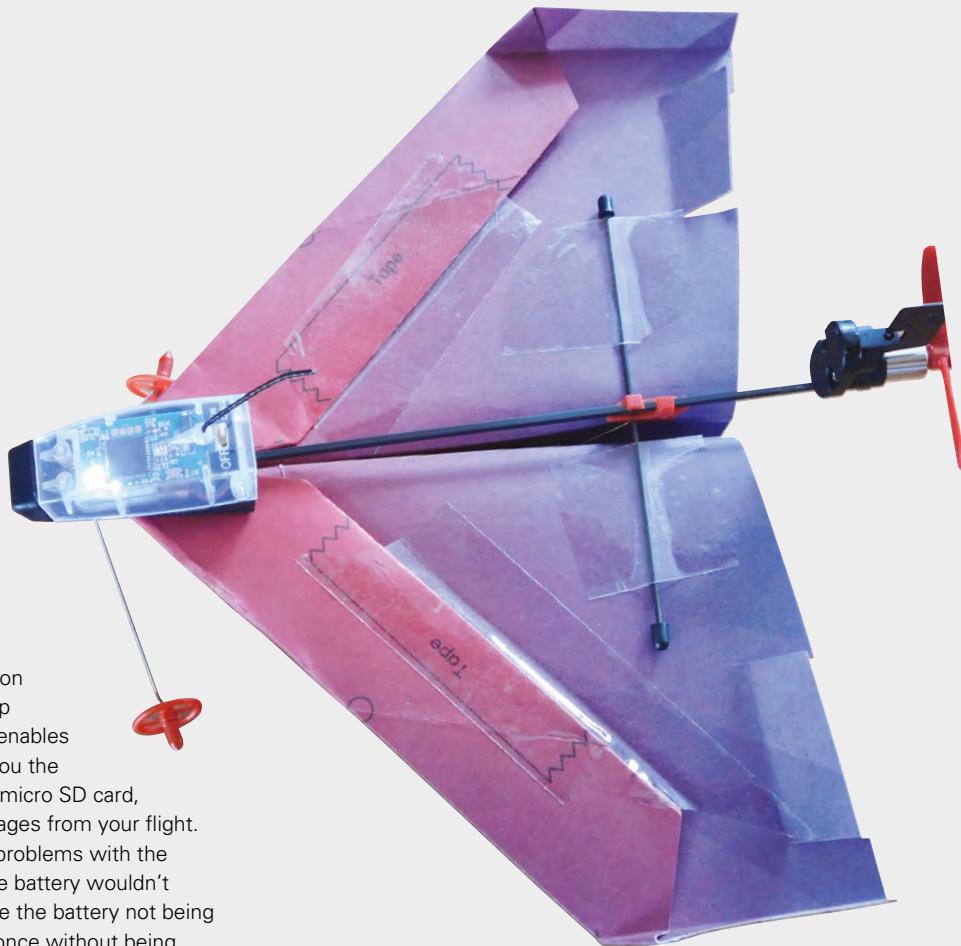
**Below** The X FPV is a larger, more serious craft, and gives the user the chance to record video

The plane connects to a phone app (available free for Android and iOS) via Bluetooth. There's a slider for thrust, and you can turn by leaning the phone side to side. The steering is pretty tricky in an all-or-nothing kind of way.

You'll need quite a big open space to fly the plane (we discovered this after having to retrieve it from a neighbour's garden). It's not that fast, but as it can't slow down, slight issues with steering get out-of-hand quickly. PowerUp recommend a grassy field at least 150 metres in diameter. For most people this will mean going to the local park, which isn't a bad idea, but only if it's quiet enough to not risk hitting other people. This isn't a quadcopter that's easily stopped on landing. Once it's launched, it's going to keep moving forward, and at first you'll probably have difficulty controlling it. Fortunately, the Dart is quite light so you're unlikely to injure someone, but that's no excuse to risk hitting members of the public. Bear in mind that any dogs in the area are likely to seek out and attack low-flying planes.

As the main body of the plane is just folded paper, you can put your aeronautical ambitions to the test, and design your own planes. There's even a website where you can upload and share your designs with other users, and occasional contests to put your designs through their paces.





The PowerUp Dart is for tiny planes, but it has a big brother, the PowerUp X FPV. This has two motors, a much bigger chassis and includes (as the name suggests) a first-person viewpoint camera. This sits atop the unit, pointing forward, and enables you to stream footage, giving you the view a pilot would have. Add a micro SD card, and you can record video or images from your flight.

We did have a few teething problems with the X FPV. Firstly, we found that the battery wouldn't charge, but this turned out to be the battery not being fully inserted. It clicks in place once without being fully in; it needs to click twice (and the battery be level with the back of the PCB), before it will work.

The second problem we had was connecting to the app. This is done via WiFi (rather than Bluetooth as in the Dart). This failed to work for several attempts, before suddenly connecting and alerting us to the need to update the firmware on the craft. Once this was done, we were able to connect straight away again.

### FIRST-PERSON FLYING

The X FPV is much bigger and heavier than the Dart, and will really annoy anyone you hit, and possibly injure them, so you really do need a secluded open space. Both the Dart and the X FPV take some time to learn to control. First, you'll probably find that the craft struggle to fly at all, and this means it needs a few tweaks to the ailerons. Bending these up helps counteract the weight in the craft's nose, but bending them too far up causes a lot of drag. You'll probably need a bit of trial and error to get this right. Despite some hard crashes, we didn't damage either of the planes, and even the paper hull was able to withstand several heavy crashes.

Once these are adjusted, it's a case of mastering the controls. Throttle and left and right turning give

you quite a good level of control (though not as much as you'd get on a craft with more degrees of freedom, such as controllable elevators and ailerons).

Ultimately, the test of something like this is: does it make you smile? For us, the answer is yes. They're great fun to make, hack, and fly. There's the childhood glee of seeing a paper aeroplane buzzing away, and then the interest in seeing how different designs fly, and of course, the pleasure of controlling a flying machine.

The biggest disadvantage to these flying machines is the amount of open space you need. City dwellers should think about whether they can fly them safely before taking the plunge. With that in mind, the PowerUp series is an easy and fun way to get into building model aircraft. It gives you the chance to try out different designs, without having to worry about the electronics setup. You might find that you want to move into custom-designed hardware in time, or you might continue to enjoy the simplicity of the PowerUp. Whichever route you end up going down, this is a great way to start. Now, get out and take to the skies... □

**Above** The smaller Dart is more manoeuvrable and its light weight makes it easier to adapt to your own models

### VERDICT

An easy and fun way to create flying machines.

**L** **8** /10

# Game Zip 64

Program your own games for playing on the go

**KITRONIK** ♦ £39.98 | [kitronik.com](http://kitronik.com)

By Ben Everard

 [ben\\_everard](#)

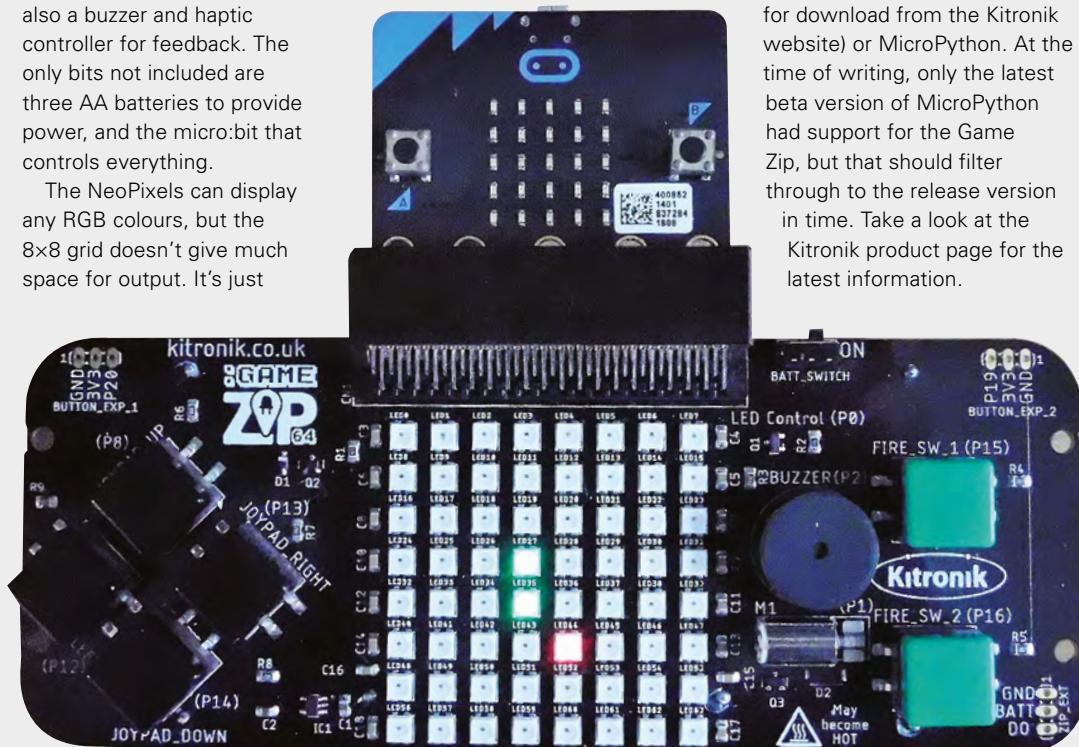
The Game Zip 64 is a breakout board that converts a micro:bit into a games console. Well, when we say games console, don't expect to challenge the graphics on the latest PlayStation, or for that matter a Nintendo Entertainment System. Even our yellowed and ageing Commodore 64 can outdo the graphics powers of the Game Zip 64, but it is a little less portable. This is a games console stripped almost all the way back. For a display, it's got an 8x8 grid of NeoPixels that you can control using six buttons. There's also a buzzer and haptic controller for feedback. The only bits not included are three AA batteries to provide power, and the micro:bit that controls everything.

The NeoPixels can display any RGB colours, but the 8x8 grid doesn't give much space for output. It's just

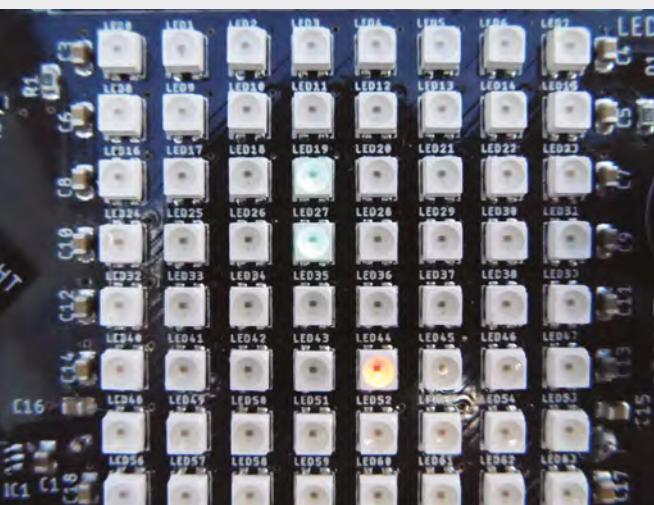
enough space for basic games – Snake and Pong are obvious examples, and it just so happens that these are the example games that are available for download. You can still use the LEDs on the micro:bit itself. These could be useful for displaying meta information, such as the current score or the number of lives remaining.

## GET CREATIVE

The Game Zip isn't for downloading other people's games, though, it's for creating your own. You can program it using either MakeCode (blocks for the specific hardware are available for download from the Kitronik website) or MicroPython. At the time of writing, only the latest beta version of MicroPython had support for the Game Zip, but that should filter through to the release version in time. Take a look at the Kitronik product page for the latest information.



**Right** ♦  
The micro:bit slots in the top like an old-fashioned games cartridge



With this support in the main languages of the micro:bit, it's easy for anyone with experience on this platform to get started writing games on the Game Zip. You do have to be able to think of your game in terms of a grid of pixels, rather than manipulate sprites as you might in other game development environments, but given that you're limited to an 8x8 grid, everything stays quite simple.

Playing on the bare PCB does work, but there's a bit of flex in the board, and it's going to be vulnerable to knocks and spills if you use it as a portable games centre. Fortunately, Kitronik provides plans to a laser-cuttable enclosure that you can build to

**“Simplicity can be both a blessing and a curse. As the display options are limited, this automatically simplifies the games that are possible”**

make your Game Zip tougher. We'd recommend doing this if you're going to use it for anything more than light development. You can also laser-cut (or buy) matching cases for your micro:bit, to keep everything safe and sound.

You don't have to limit yourself to just the hardware that's included by default. Although this hardware takes up all the pins, it does break out the I<sup>2</sup>C bus, so you can hook up more hardware that understands this protocol. For example, this could include adding extra buttons for two-player games.

If you're a teacher or working with young makers learning to code, there's a series of lesson plans to help you get started. You can take a look at these

on the Kitronik page, and see if they'll fit in with the curriculum you're working through.

### BACK TO BASICS

Simplicity can be both a blessing and a curse. As the display options are limited, this automatically simplifies the games that are possible, and without even the possibility of complex graphics, users can get started easily and focus on the programming rather than the graphics. However, such limited graphics can put people off. This controller certainly pushes the boundaries of how simple a games controller can be yet still be fun to create and play with.

In our opinion, it's too limited to have popular appeal and will only attract a niche audience. Of course, this isn't a bad thing – what the Game Zip does well (portable games using a small grid of multi-coloured pixels), it does really well. It's easy to get started and fun to play about with. For this price, it's a great way to have a retro-style portable console, especially if you're already familiar with the micro:bit.

The integration with MakeCode and MicroPython mean that you can be up-and-running really quickly. The example games give you a place to get started, and provide plenty of scope for adding extensions to play around with in other ways. □

#### Left ↴

The array of pixels is bright and clear, but quite limited

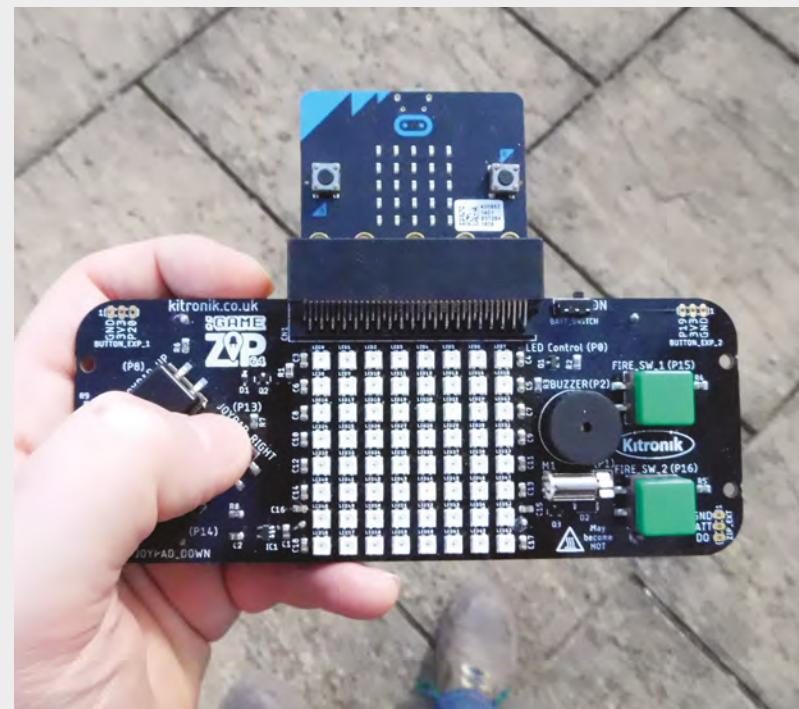
#### Below ↴

The Game Zip 64 fits comfortably in our hand for playing on-the-go

### VERDICT

Limited graphics, but still scope for some great games.

**8/10**



# KKMoon knife-sharpening system

Sharp blades are safer and easier to use

**KKMOON** £18.99 | [kkmoon.com](http://kkmoon.com)

By Ben Everard  ben\_everard

**S**harpening a knife can seem like it should be incredibly easy. Get a coarse surface, scratch over the edge and voilà, a sharpened knife. However, despite the fact that this is the basic process, there's a huge amount of nuance that goes into creating a good edge which is both sharp, and lasts.

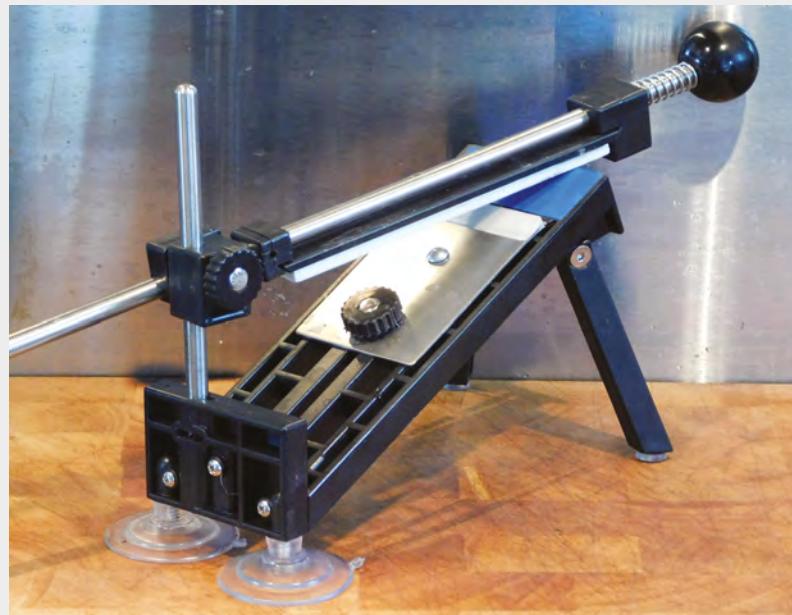
The first basic problem is being consistent and accurate. A good edge consists of two flat surfaces meeting at a point. Creating this by hand requires very accurate hand movements. Typically, what you'll end up with is two surfaces curving in towards a point that won't get sharp because of this curvature.

This knife sharpening jig then, is simply a way of holding the stone at a particular angle to the blade, allowing you to sharpen with confidence. It's a pretty simple idea. There's a pivoting upright rod that you can lock the whetstone holding rod to. Put a blade in the adjustable blade holder and then, as you move the gritstone, it can move in two dimensions, but not the third. This means that, as you move the stone, you sharpen the knife at a precise angle.

The sharpening kit comes with four stones from 180 to 1200 grit, and you can move up through these various coarsenesses to get to a final, sharp blade. 180 is very coarse. We tested this system on very abused blades, so started with the 180 or 400, depending on the knife. If starting with a blade that's only a little dull, you could skip straight to 1200.

The jig has a bit of wobble in it, and you have to be a bit careful to not rock it too much. However, you should sharpen slowly and carefully anyway, and it's certainly possible to use this effectively.

The stones are a little softer than some top-quality stones we've used in the past, so they may not last



forever, but definitely showed no problems during our test sharpenings.

The way the guide and stone are set up means this is only really suitable for knives or other long, straightish blades. We wouldn't recommend this for chisels, drill bits, or other tools.

Fundamentally, the test of a knife sharpener is in the blade it creates, and the traditional test for this is shaving your arm. We were able to create a blade that did this, but only just. This tool struggles to get super-sharp blades because it doesn't come with high-grit honing stones. That said, a blade capable of shaving is unnecessary for most uses, and this produces a blade which is easily sharp enough for general use. You can get smoother stones for this guide, or you could finish the blade by hand if you really need that sharpness.

This jig doesn't take all the skill out of sharpening a knife, but it does make it much easier to get started. The kit felt a little flimsy, and we have some concerns about its durability if under heavy use, but for casual knife sharpening, at this price, it's hard to beat. □

**Above** While there is a bit of wobble, we found the jig stable enough to be effective

## VERDICT

The best value knife sharpening system we know of.

**9/10**

# Women in Game Development: Breaking the Glass Level-Cap

(Edited by) Jennifer Brandes Hepler ⚡ £36.99 | [crcpress.com](http://crcpress.com)

By Richard Smedley

 @RichardSmedley

**A**s we watch our young daughters, nieces, and sisters at maker events, playfully learning about technology, and encourage them into an interest in STEM, we see a welcoming maker community, which embraces diversity. But look beyond, and you soon see that technology has a problem.

Most particularly, game development has a toxic problem. This book was written in the aftermath of Gamergate, an outpouring of online hatred towards women, severe enough to make the mainstream

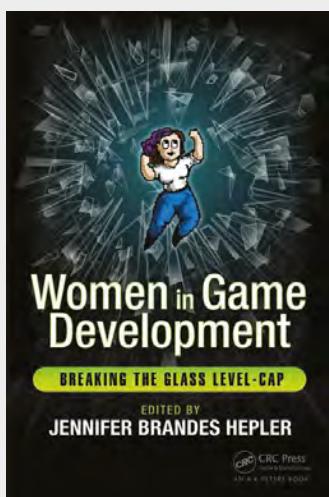
press, while many prominent game publishers ignored events, refusing to speak out, and seeming to give licence to the growing outpourings of bile.

Many fields of software development are dominated by young males, and games development in particular became a shelter for the emotionally immature, who are afraid of growing up; afraid of letting in what they don't understand (and too often they understand very little). A diverse and welcoming workplace is not just good for profitability, with women making up the majority of games purchasers, and older women outnumbering the young men at whom most games seem to be marketed, but for the culture of a company. Treating people with respect at work shouldn't be an optional extra.

This book is written by and for women who love games, women who make games. With no single narrative, and a striking collection of achievements, it's a valuable chronicle of diverse routes into the industry; a sad but often positive collection of struggles against prejudice; and a great introduction to many of the personalities behind games.

People like Megan Gaiser who, told that girls didn't like computers or play video games, ignored a conventional wisdom that was more convention than wisdom, and took the Nancy Drew series of games to market, and on to outsell the Harry Potter and Lord of the Rings games for seven consecutive years.

These are some exceptional women, but: "I don't want existing as a woman in the games industry to be any more remarkable than existing as a woman in dentistry or accounting," says Elizabeth Sampat, "I don't want to be special or unique or exceptional. I want to be mundane." □



## VERDICT

A fascinating collection of passions for and battles in gaming, and a practical guide to getting into the industry and staying there.

10/10

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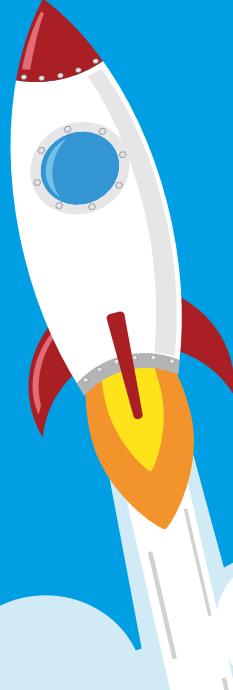
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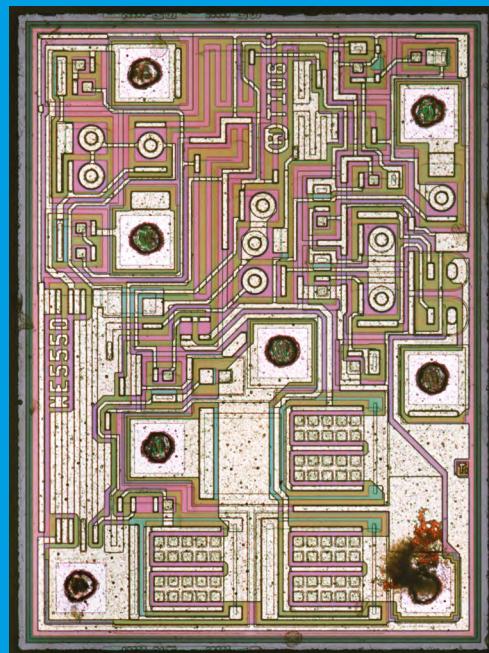
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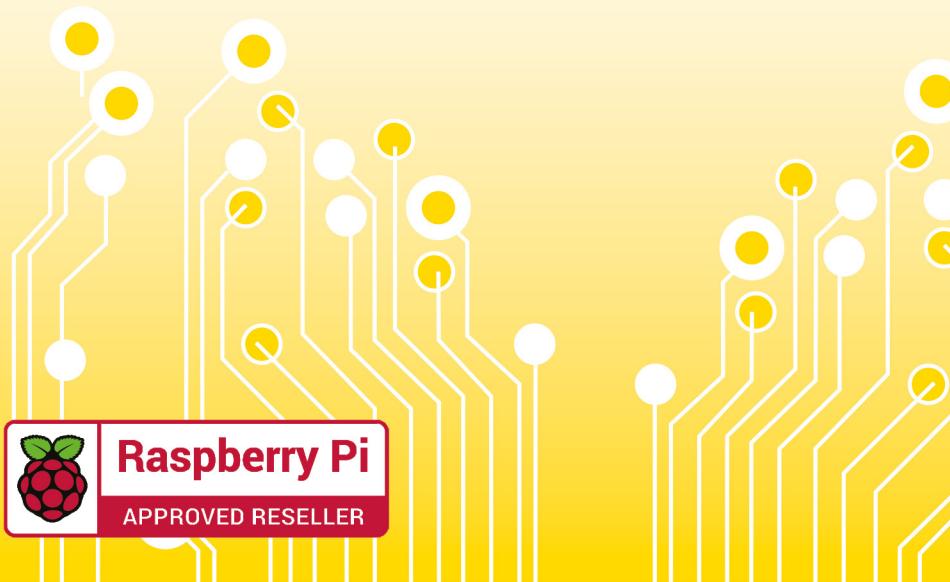
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