MAKE | BUILD | HACK | CREATE

HackSpace

TECHNOLOGY IN YOUR HANDS

CUSTOM CARRY-ON

Sew your own messenger bag

CIRCUIT SCULPTURE

Free-form LED creations

BOAT BUILDING

How one maker took to the water

60

Expert tips for better

3D PRINTING

LASER CIRCUITS

ETCH YOUR OWN PCBs

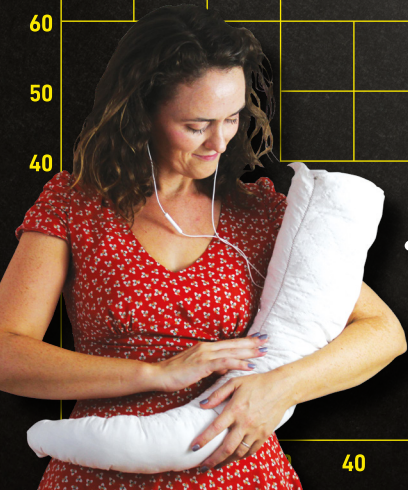## MICROCONTROLLER GRAPHICS

ADD VISUAL EFFECTS IN CIRCUITPYTHON

Pet Tentacle

Sew, solder, and program a cuddly, purring tentacle

Nov. 2020
Issue #36 £6

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Raspberry Pi PRESS

YARN ARTIFICIAL INTELLIGENCE BENDING METAL CAMERAS

Welcome to HackSpace magazine

3D printers are curious tools. In some ways, they're very simple. Three motors move a print head about in space, and a fourth motor – coupled with a heater – deposits hot plastic wherever you tell it to. However, this simplicity belies a huge amount of complexity. There are many layers of things that can stop you getting good-quality parts out of your 3D printer, and it can take a bit of time and practice to know exactly what to do when things aren't going to plan. In

> In this issue, we're gathering up all our experience into **some top tips that will, hopefully, help you skip** the pain and go straight to great parts

this issue, we're gathering up all our experience into some top tips that will, hopefully, help you skip the pain and go straight to great parts.

Of course, it's not all hot plastic. This month also sees the start of Helen Leigh's series on music, and it starts with a purring tentacle – it's a bit hard to describe, but it's weird, and wonderful. See for yourself on page 90.

BEN EVERARD
Editor ✉ ben.everard@raspberrypi.org

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PAGE **46**
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Contents

Cover Feature

60 TIPS
FOR BETTER
3D PRINTING

**Improve every single aspect
of your printing game**

34

Tutorial

3D printing

80 Make things to help you
make better things

48

Sonic experiments

90 Craft a cuddle baby Cthulhu to keep you warm in the night

70

06
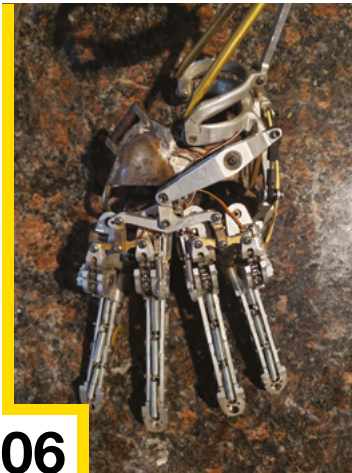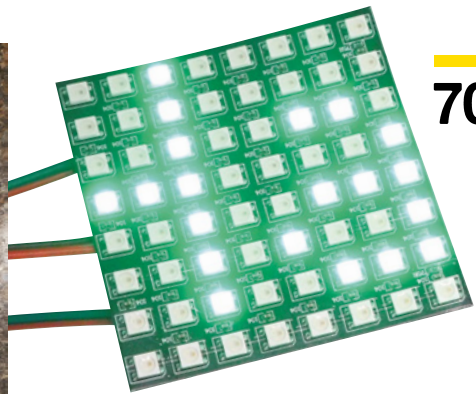
102

Interview
Joshua Zimmerman
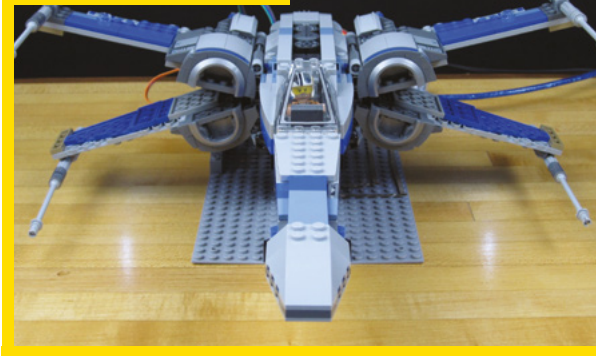
56 On the genesis of a STEM education company – Brown Dog Gadgets

20

Contrived objects

By **Leonardo Ulian**   ↗ **hsmag.cc/40eO2g**

Pareidolia is the psychological phenomenon that leads our brain to find familiar things in unrelated objects.** That stain on the ceiling that looks like a squirrel? Pareidolia. Faces in clouds? Pareidolia.

Italian artist Leonardo Ulian's contrived objects play with this concept. In his own words: "The egg shape of the 'head' of these vintage rackets reminded me of something familiar, but at the moment lost.

"The result is a composition that vaguely resembles a human face made from a recycled object from the past, the racket, clashing with the rest of the elements, electronic parts, and the found objects." →

Right ↗
This is part of a series that Leonardo's made during lockdown with things he had lying about in his studio: electronic components, varnish, wires, Perspex, bits of stone, and tennis rackets

Autobot LED pin badge

By **Fabrizio Barragan**   **hsmag.cc/oynuM0**

We love 1980s nostalgia, so here's a flashy Transformers-themed pin badge. It's a simple design, with two LEDs, two resistors, a 1 µF capacitor, a battery holder, and a switch. But there's also a Microchip Technology PIC10LF322, which Fabrizio's used to program different flashing sequences using the chip's PWM functionality. →

Right ⌐
PCBs don't have to be complex to look great.

Myomechanical hand

By **Ian Davis** ⬀ **hsmag.cc/Gcus5A**

After an accident, Ian Davis lost the four fingers on his left hand. If he had lost his palm as well, his insurance would have paid out for a prosthetic hand. But he didn't, so thanks to the USA's baroque healthcare system, he's had to make one for himself.

Actually, he's not just made one – Ian's iterating through wood, 3D-printed plastic, and now aluminium designs, constantly refining for durability and dexterity. This is the current version, which he's been using for four months now. Ian says it gives him biofeedback from the three points of articulation – the wrist cuff, the fulcrum at the wrist, and the end of the metacarpophalangeal joints on the palm side – which enables him to feel exactly how hard he's gripping something.

Ian's working on a new version with redesigned joints and slightly shorter fingers to give a stronger grip, and also planning a version with electronically controlled clutches so he can move individual fingers. →

Right ⬀
Ian's also made a partial prosthetic with a Milwaukee impact driver

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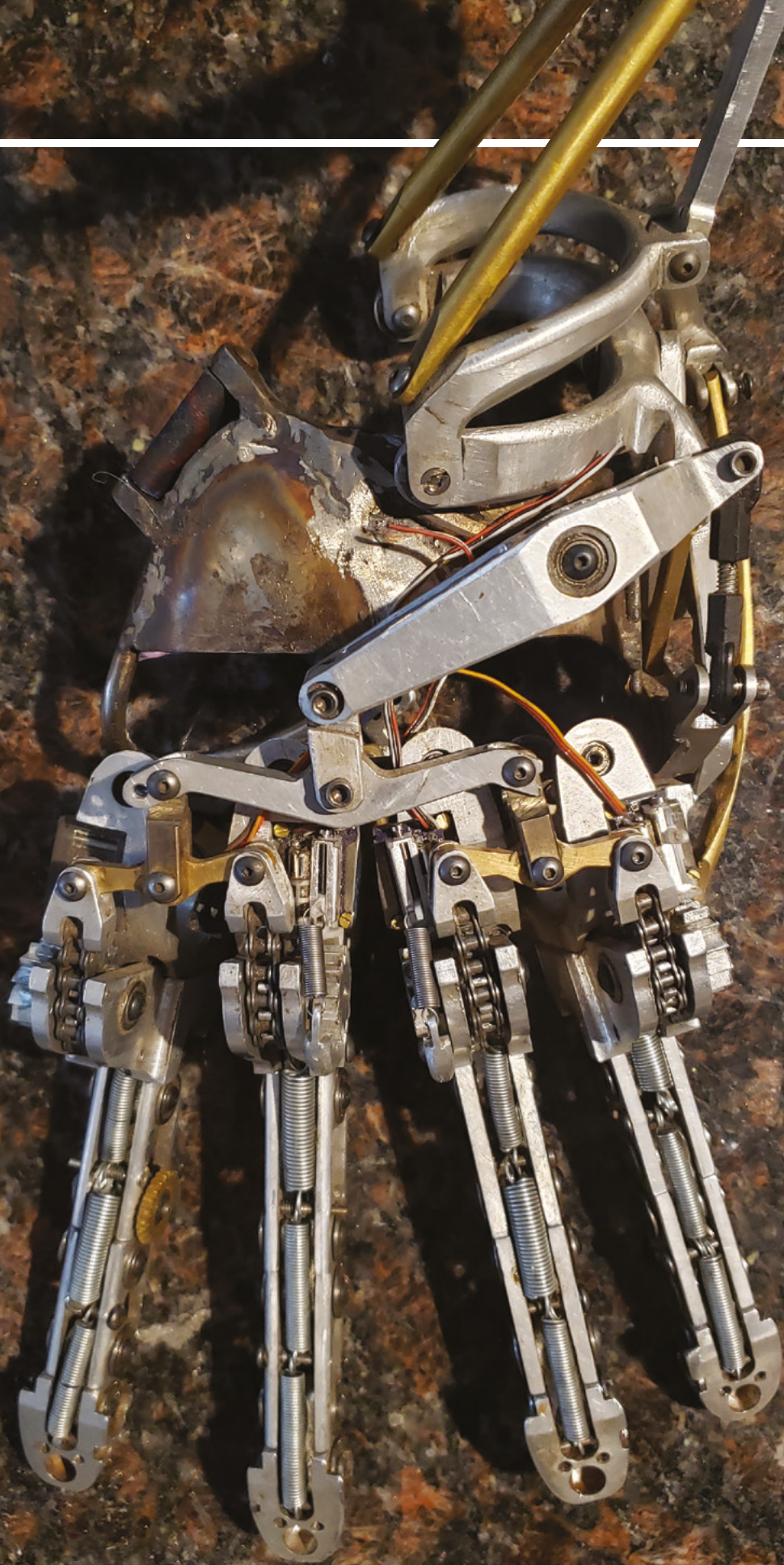
Portable 3D printer

By **Nick Li**   **hsmag.cc/ZpfPqu**

"**I** **built this printer to fulfil a need: printing on the go.** And not just on the go, but anywhere on the go. This meant that existing 'portable' 3D printer designs were basically out of the question – a folding printer can't print during travel, and the requirement of an external filament roll, outlet, computer, and SD card was quite limiting. It's also not as if folding printers are small – maybe they'd fit in a suitcase or a large backpack. If I were in the middle of the Sahara on top of a mountain and I needed a 3D printer, well, I'd be out of luck.

"So, this printer solves all of those problems. A built-in 120 Wh battery keeps it printing for three hours, long enough for several prints in the 50×50×46 mm build area. The inclusion of an OctoPrint hotspot running on a Raspberry Pi 3B means that I can print from anywhere, just using my phone. A mini spool filament holder is integrated into the 3D printer's design as a simple extension of the frame, and the printer's fully self-contained design eliminates any worries about saving extra space for accessories. The bed stays within the 3D printer's petite 195×150×165 mm frame (excluding Bowden tube)." →

Right ↗
Amazingly, Nick built this printer as a high school project
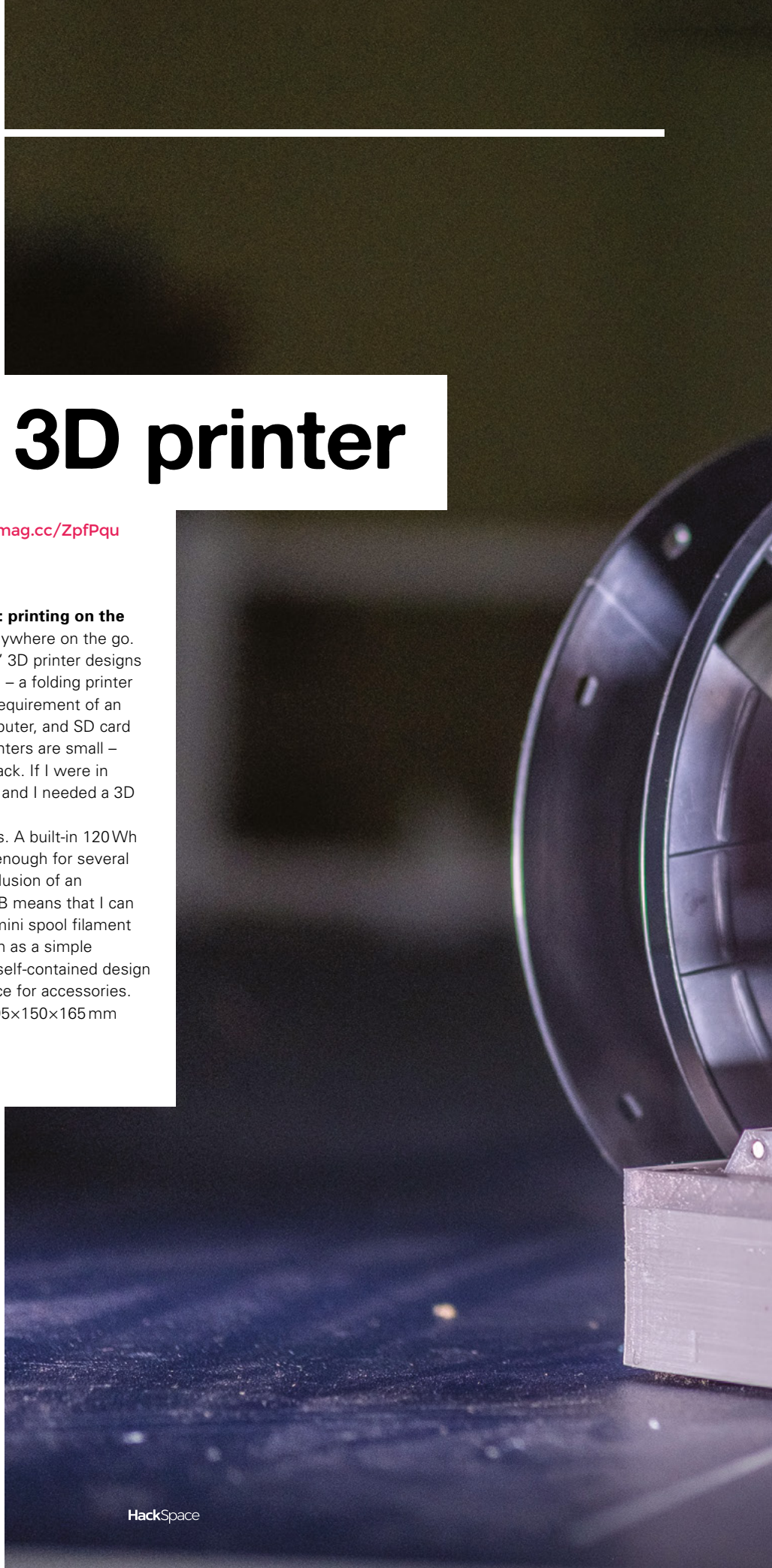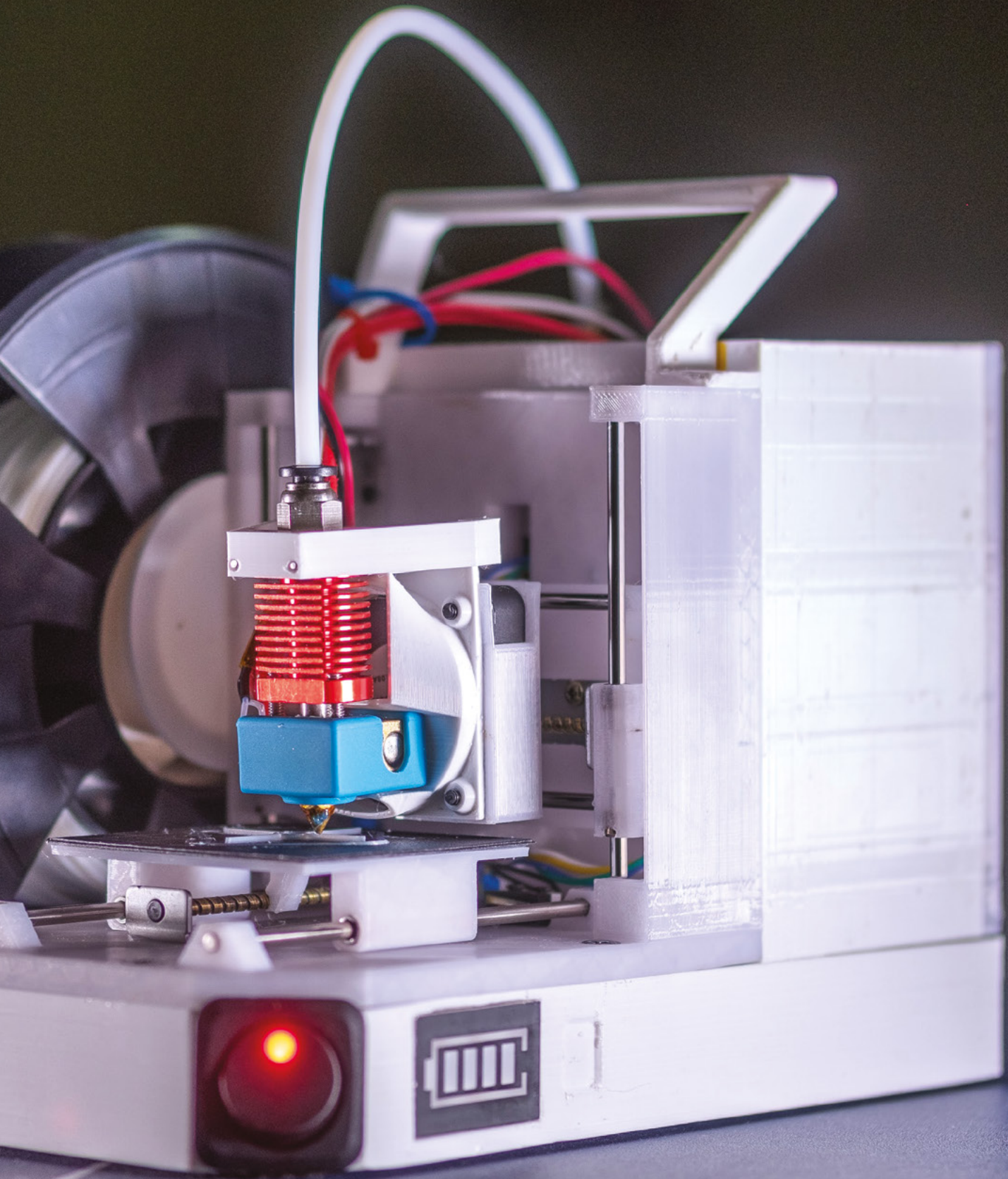
The One Ring Mobile

By **IJustLikeMakingThings**   hsmag.cc/DJImoM

The *Lord of the Rings* **is, without doubt, one of humankind's finest achievements.** It's only right that we pass on this knowledge, and love for the characters of Gandalf, Strider, and Frodo, to the next generation. The characters are made of felt; the ring is bent-wood, laser-engraved with the inscription on the ring worn by Sauron the Deceiver as he sought to conquer Middle Earth. ▫

Right ↗
Halflings sleep well under the watchful eye of the King of Gondor

Wooden data disc

By **Jon Bumstead**   hsmag.cc/Rro2GN

T**his is, essentially, a giant CD, in that it stores digitally encoded data which is read by lasers.** There are a couple of differences, though: the first is that the depressions in a CD are too small to see with the naked eye, while the holes in Jon's data discs are much bigger. This means, logically, that you can't fit anywhere near as much data on one of these as you can on a CD.

That leads to the next difference: audio files tend to be huge, so to store meaningful data, Jon's had to use a smaller file format: text. Each of these discs stores a text message, read by two lasers, and displayed on the LED array fixed to the front of the machine.

To get data off the disc, there are two detector modules, each consisting of a laser and a photodiode. Light is either reflected off the surface of the disc as it spins, or isn't, which gives the 0s and 1s needed for digital data. ◻

Right ⌐
Jon added a linear actuator to move the data-reading laser module up and down, so it can read multiple rows on the disc

Objet 3d'art

3D-printed artwork to bring more beauty into your life

It makes perfect sense to personalise your tools. A woodworker, say, might be holding his mallet for hours every day, so what to a casual sawdust maker may seem like an extravagance, is actually an expression of pride in a job well-done.

So why do so many of us sit in front of the same old keyboard day after day, when we could add a bit of luxury? That's what Billie Ruben's offering with her brilliantly simple embroidered keycap design. It has 25 holes arranged in a 5×5 grid, so that you can add thread and customise it with whatever plush tactile design you like.

A word on the printing – because of the fine detail involved in this design, a standard FDM printer is unlikely to perform well enough to make these usable – Billie used an Anycubic Photon resin printer to create these examples. ◻

↗ **hsmag.cc/PtAkVz**
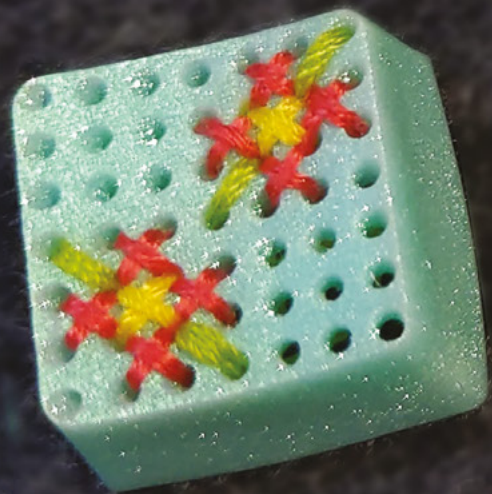
Meet The Maker:
Jack Daly

A new generation of retro gaming

When most of the HackSpace magazine team were teenagers, we were busy messing with things that we shouldn't, learning the guitar, and pondering the merits of Blur vs Oasis.** What we weren't doing was designing and building a programmable handheld games console, launching it on Kickstarter, and taking in 205% of our target funding. That's what Jack Daly is doing with his 8BitCADE XL console, an Arduino-based throwback to the glory days of Zelda. Which led us to our first question: what on earth is a 17-year-old doing playing Zelda?

"There are two sides to my love for retro gaming. One is actually playing them – I love their addictive nature. The second one is more from a coding standpoint – they had so many hardware constraints

> **I made my second arcade machine also as a school project,** using recycled plastics, and I used coffee grounds as part of the case

to deal with. If you see some of the really early games, they were using lines and letters and things to make text adventures. It's so basic, which makes it accessible.

"My dad grew up with these retro games, so that was also an influence. He introduced me to some of the more mainstream ones, like Sega. I have a

Nintendo DS, and I remember playing Sonic the Hedgehog, which was a really famous game for the Sega Genesis, things like that. Things like Mario; that was the bridge from where we are now to retro games back then. Most people dip into Mario, and they dip into Sonic – I decided to walk the bridge and look into Space Invaders and stuff like that.

"I've made a few games machines – they keep getting smaller. My first arcade machine was a two-player arcade machine, with a much larger cabinet that had a screen built-in. That was my first introduction to arcade gaming, and I made it as a school project.

"I made my second arcade machine also as a school project, using recycled plastics, and I used coffee grounds as part of the case. It was a kind of a small, one-player arcade machine. The idea was to do with sustainability, and show how the company was using waste coffee grounds to create something exciting for everyone. Children love games, and adults love nostalgia.

"When I made the arcade machines, I did think maybe I could sell these? Teachers were coming in from other departments on their breaks just to play the console, which was hilarious.

"My dad was head of DT then back in that school. We created and designed a wall-mounted arcade machine that had a coin slot, with the idea that any money we raised would go to charity. The DT department slowly evolved into sort of a place where people could come, which was brilliant.

"With the first iteration of the 8BitCADE, we were focusing more on achieving an arcade sort of →

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Above ⬀
The 8BitCADE
Original, Jack's
first handheld
gaming console
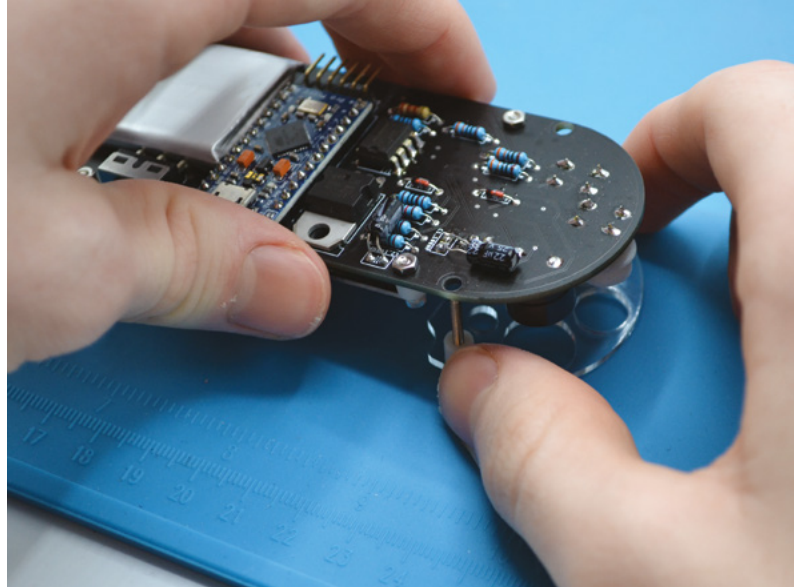
handheld console, and you can see that from the design. It's quite blocky. It has got the sort of maker look of the acrylic, and you can see how the XL has come about from it. We started with a small screen, just buttons, trying to get the hardware there.

"We were trying to make the unit as cheap as possible so that schools could use it and integrate it into their curriculum. That was the aim of the 8BitCADE Original. That's where the feedback came from – it started getting used in lessons at my school. Pupils in year 8 and 9 were creating their own 8BitCADE, soldering it up, and then coding games on it, and that's where we realised we could break it down into three areas: Code, Make, and Learn – which is how we divide our efforts. We put a lot of effort into ironing out the learning process.

"There's a community of game developers and makers called Arduboy. If I were to start again from

Right ◈
We asked Jack what his favourite retro game is. The answer? Donkey Kong

scratch, I'd involve the online community more. The 8BitCADE is open-source, so it might have developed faster with early involvement from the community. When I first started, I was focused on a small group of users, because I thought of them as the people who would be using it, but what I should have done was open up to the community a bit more. When I realised that, I began to do it, but I wished I'd done it a bit earlier on.

"I saw the online world and how many developers and gamers were on there, and utilised that asset. Currently, our focus is [on] fulfilling the Kickstarter orders. But we are in the process of developing some other range of products, and from there I'm trying to involve the community a lot more at an earlier stage. I won't say I'm learning from my mistakes, but learning from the experience of producing the XL, and how we can create a more dynamic product that includes the community.

TEAMWORK MAKES THE DREAM WORK

"In terms of the games system, the programming, we have had a lot of feedback. I started developing my own games for the XL as I was making tutorials, which really helped me iron out my programming,

> " **I would say I'm an adequate programmer. I'm a beginner,** so opening up to the Arduboy community was great "

which was brilliant, but I also had to open up to the community and say, 'guys, I need help with this; can you explain this or that concept?' There's an Arduboy member called MrBlinky, who was a great help – he made something called the Arduboy-homemade-package. The origins of the 8BitCADE XL games loader is MrBlinky's homemade package. What he did allowed 8BitCADE to include a 200-game menu system. From there, that's where we started to include the community.

"I would say I'm an adequate programmer. I'm a beginner, so opening up to the Arduboy community was great, because they're professional programmers.

"Whenever I've tried to learn programming, I've always felt that if I'm copying someone else's code, I'm not a programmer. So, whenever I was writing some code for myself, I tried to start on a blank →
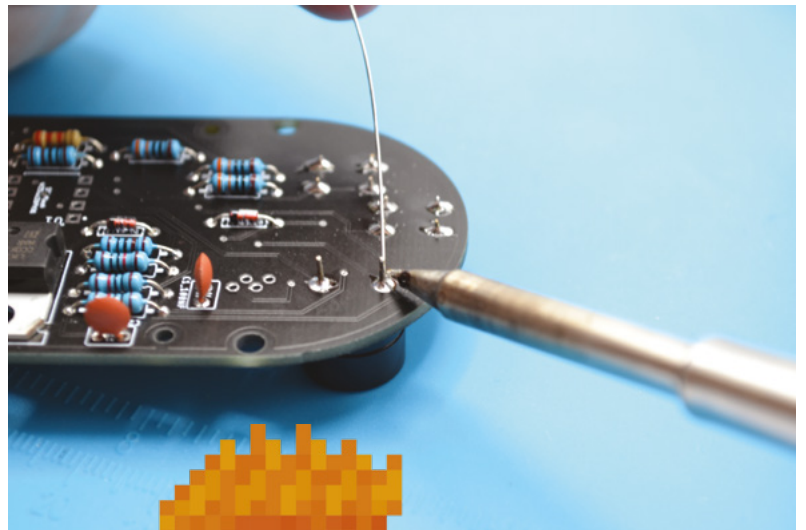
Above ◈
The 8BitCADE XL is designed to teach electronics and games development skills

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page, because I thought that that's what programmers do. As you go on, you realise that there are so many communities online. People put their code up overnight, and the next day they'll have 50 different copies of the same code that people have said, 'you can do it this way' or, 'you can do it that way.'

"But it has been hard to adjust. You begin to lose ownership of your code, but you've just got to realise that that's what open-source is, and that's what community is.

TOOLS

"We're shipping the 8BitCADE XL with a toolbox that contains all of the tools that you need. The main tool is the soldering iron. We've recently updated the

> **You can take the toolkit and the coding with you, and** knowledge that you get from coding the 8BitCADE

toolbox, and added more tools for the same price. To our backers, you're brilliant, we've reached 200% of our goal, so we're adding tools that suit the project.

"What I wanted to do with the toolbox was to make it for anyone, absolutely anyone who's doing any electrical project. When they get it, they can build their XL, and hopefully with that knowledge, the XL and the toolkit are your door into the electronics world. You can take the toolkit and the coding with you, and knowledge that you get from coding the 8BitCADE, and go forth and build your own things.

"What's in the toolkit is a soldering iron, a roll of solder, a solder sucker, side cutters, a full screwdriver set, and long-nose pliers. We could have said: 'here's the one particular screwdriver that you'll need to build this one kit', but our goal is to equip people to go on and learn through other projects, so we added that versatility.

"We wanted to promote self-learning. A lot of the skills that I've learned have been self-learned – the Adobe package, Fusion 360, and SolidWorks, and I believe that's how a lot of things should be learned.

"I wanted to take that self-learning principle and put that into 8BitCADE. I believe, with passion, that you can really go places if you're self-learning. If you're driven, you'll go faster. That's what the toolkit does – opens doors in the electronics world." □

The subtle art of noticing

What you look for is what you get

Lucy Rogers

🐦 @DrLucyRogers

Lucy is a maker, an engineer, and a problem-solver. She is adept at bringing ideas to life. She is one of the cheerleaders for the maker industry, and is Maker-in-Chief for the Guild of Makers: **guildofmakers.org**

How many times have you lost your keys 'somewhere' in your house?** Or your glasses? Or, you can't find the scissors? And you're sure you had the tape-measure moments ago – but it's now disappeared.

Other than making (or buying) a gismo that attaches to your important items, the answer is, apparently, to visualise it – rather than verbalise it. Imagine what the keys look like, rather than saying "where are my keys?"

However, I am not great at visualising an object in my mind's eye. I get a sort of semi-transparent and ethereal *thing*. What do you get? Try to imagine a red star. Do you get a solid, bright, five-pointed shape, rotating in a GIF-type manner? Or is it 2D and coloured in with crayon? Or is it Betelgeuse – the slightly orange pinpoint of light on Orion's shoulder in the night sky? Or, do you see nothing at all? My visualisation is the ghost of a Christmas tree decoration that we had when I was a child.

As the 'just visualise' it technique can be challenging, I go for the 'what colour is it?' technique. My tape-measure is orange. When I know I am looking for something

orange, all the orange things pop out at me – that handle on the G-clamp, the label on the glue – and, oh look, poking out from under that pile of offcuts, it's the tape-measure!

I suspect the same technique happens with other things too. Every morning I post a photo of something I have spotted in nature with a 'Good Morning' tweet. Knowing that I want to send such tweets makes me keep my eyes open for potential photographic subjects. I am sure I have seen flowers and insects I would never have noticed otherwise.

> **I am sure I have seen flowers and insects I would never have noticed otherwise**

But it also works on not such nice things. For example, crisp packets had been left littering the footpath through my local meadows. After a couple of times walking past them and being disgruntled at the litter-louts, I took a bag, and next time I passed them, I picked them up and threw them in my own bin. However, now I am noticing litter EVERYWHERE.

I need to 'reframe' what I look for. If I don't want to just see unfinished projects or DIY that needs to be done, I need to start looking at the jobs I have finished, the things I have made, and celebrate those!

Now, what shall I focus on next? But first … where did I put my glasses? ☐

Open all the way down

SkyWater PDK enables fully open chips

Drew Fustini

🐦 @pdp7

Drew Fustini is a hardware designer and embedded Linux developer. He is the Vice President of the Open Source Hardware Association, and a board member of the BeagleBoard.org Foundation. Drew designs circuit boards for OSH Park, a PCB manufacturing service, and maintains the Adafruit BeagleBone Python library.

've talked a lot about open-source hardware in this column, from PCB badge designs to the instruction sets used in the chips that go on them. It's no secret that I'm on a mission to find a computer system that is open-source all the way down to the lowest level possible – the transistor. This month, I want to share a very exciting collaboration between Google, SkyWater, and efabless that opens up a path to that future.

Two big roadblocks to open-source chips have been: access to a process design kit (PDK) from a silicon fab, and high cost to actually get chips manufactured.

The PDK files contain details about the process that is used to fabricate semiconductors. Chip designers need this information for electronic design automation (EDA) software to transform their digital logic into the physical layout of millions of transistors. Fabs treat the PDK as proprietary and force customers to sign an NDA in order to get their chip manufactured. This prevents the customer from publishing the complete chip design as open-source.

Earlier this year, Tim Ansell of Google announced a collaboration between Google and SkyWater to provide a fully open-source PDK, which can be used to create manufacturable designs in the 130 nm at SkyWater's facility. This enables the complete design of a chip to be open-source, from the HDL (hardware description language) source code describing the digital logic, to the lithographic masks used to etch millions of transistors onto a silicon wafer.

One reason that there are so few open-source chip projects, as compared to open-source circuit boards, is that the cost starts in the thousands even for decade-old technology like SkyWater 130 nm. However, there will soon be manufacturing runs you can be part of for absolutely zero cost, thanks to Google and efabless. The first run will take place in November 2020, with several more to come starting in early 2021. As long as your design is totally open-source, you can get your own chip manufactured – what an achievement for Open Source Hardware!

To learn more, I would highly recommend watching Tim Ansell's talk at FOSSi Dial-Up 2020 (**hsmag.cc/UCtRO6**), and you can also read about the SkyWater PDK on GitHub (**hsmag.cc/lZlCG4**) ▫

> ### This enables the complete design of a chip to be open-source

Letters

MAKING VS MONEY

I had to laugh at Robin Baumgarten's business model – make cool stuff, worry about the money later! What a brilliant way to approach life! It's a massive shame that Wobble Garden and Wobble Sphere are things that are meant to be touched, when we're now being told not to touch anything. I was lucky enough to see Wobble Garden when it was on show in Dundee. There were no instructions – you just knew what to do with it. Good luck to Robin and all the other artists trying to get through these times with no support from the government.

David Connor
Perth

Ben says: In all fairness to the government, Robin's based in Berlin, so the lack of support that the UK government is offering the creative arts isn't affecting him too much. I'm very much hoping that Wobble Sphere can come out of hibernation and make its way to a town near me soon.
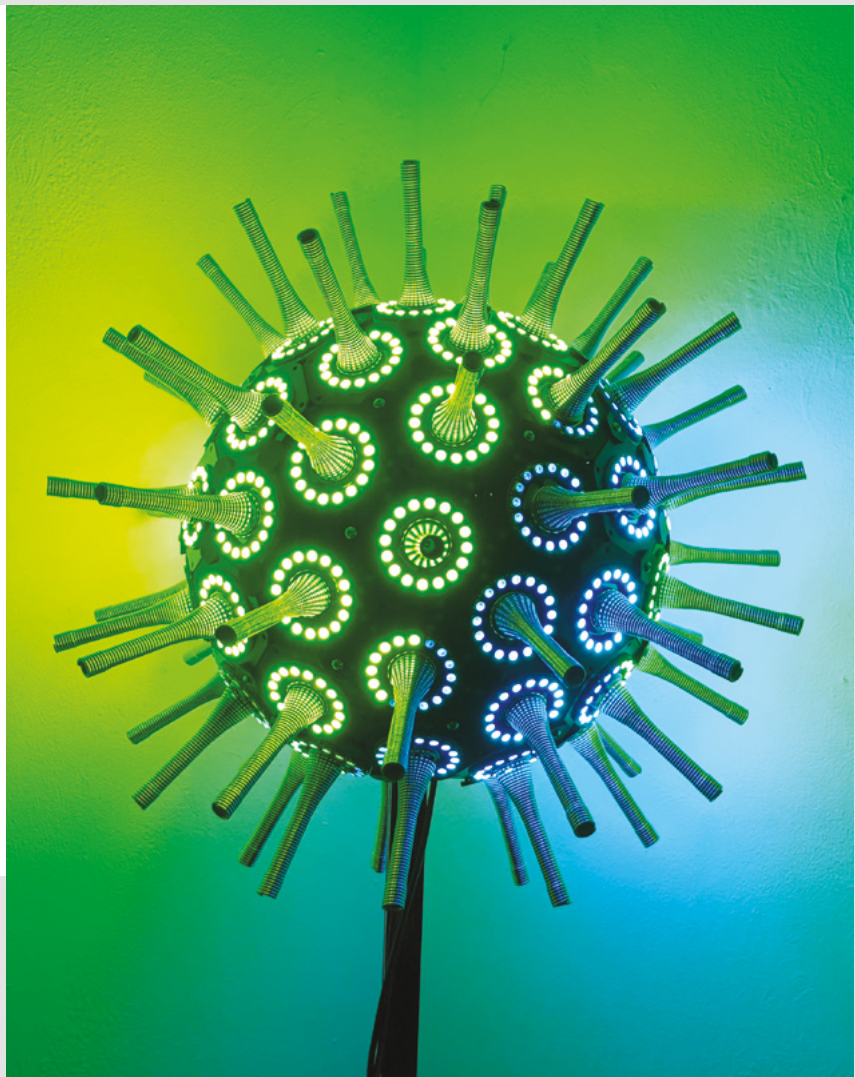
ARCADE GAMES

Your guide to building an arcade machine [issue 35] came at just the right time. I have a policy of only buying tools when I have a project in mind, and I was struggling to justify buying a jig-saw. Now the MDF quakes in fear beneath my mighty blade! Two rainy weekends and I'm now the proud owner of my own arcade machine, with the added bonus that I don't have to get up at the crack of dawn to deliver newspapers to earn the money to put in it, as I did in the 1980s.

Usman
West Midlands

Ben says: There's something weird about arcade cabinets. You could be playing exactly the same game sitting down in front of a monitor, but the moment you stand up, you're transported to another world. It's like muscle memory, taking you back to when the hardest thing in life was coming up with another 20p to put in the machine rather than car insurance, bills, etc. I'm just trying to persuade Andrew Lewis, who did a great job with the arcade cabinet build, to have a crack at building a two-player OutRun machine.

SMARTWATCH

It's possibly a bit niche, but the smartwatch you've been experimenting with over the last few issues may be just what I'm looking for. I've recently taken up running again after a few years off, and I was using a device to track my speed, time, distance, etc. Then I found out that it automatically shares data with anyone else who's using the same thing, so anyone I run past can get the beginning and end of my route (which is my home. This is deeply weird, scary, and inconsiderate of the developers. So, a smartwatch that I can program myself to do exactly what I want and not leak data because a bunch of tech bros in San Francisco didn't think about women's safety, sounds perfect.

Sarah Bauer
Pennsylvania

Ben says: You don't mention the model of fitness tracker, but I think I can guess – yes, that was appalling. But that is the beauty of open-source right there – if you want to implement a feature (or get rid of it) you can, just like that. Well, I say just like that: it's taken some work…

Battery: 58
not stepping
Steps: 32
none

CROWDFUNDING
NOW

Gameduino 3X Dazzler

Taking microcontroller graphics to the next level

From $39 | **crowdsupply.com** | **Delivery: 30 November 2020**

T **he Gameduino 3X Dazzler is an Arduino-compatible shield for adding stunning 2D and 3D graphics to your Arduino projects.** It features an FPGA and a GPU to allow you to add visual effects without pushing your microcontroller to its limits. The FPGA contains a J1 CPU – same as in the original Gameduino – but this time it's partnered with a BT815 GPU. This graphics unit gives you an OpenGL-style command set for drawing scenes that can then be rendered via HDMI. You can render up to 2000 sprites, display JPEG, PNG, and ASTC images, play AVI videos, and more.

Of course, games aren't just about graphics, and you can get input via two Wii Classic-compatible controllers. All this is tied together with software libraries for Arduino and CircuitPython.

Modern microcontrollers are capable of playing complex games, and the Gameduino 3X Dazzler gives you the ability to take this a step further. HDMI output gives us the ability to use modern screens with our microcontroller, and the GPU really opens up a new graphics world to us. All this while still retaining the simplicity of using a microcontroller-based system, rather than a general-purpose computer. We look forward to seeing the awesome games people come up with using this. □
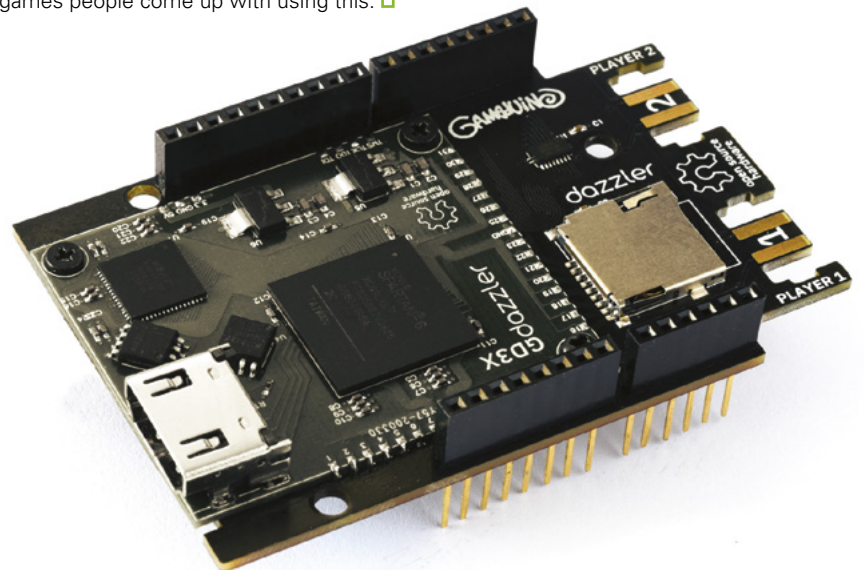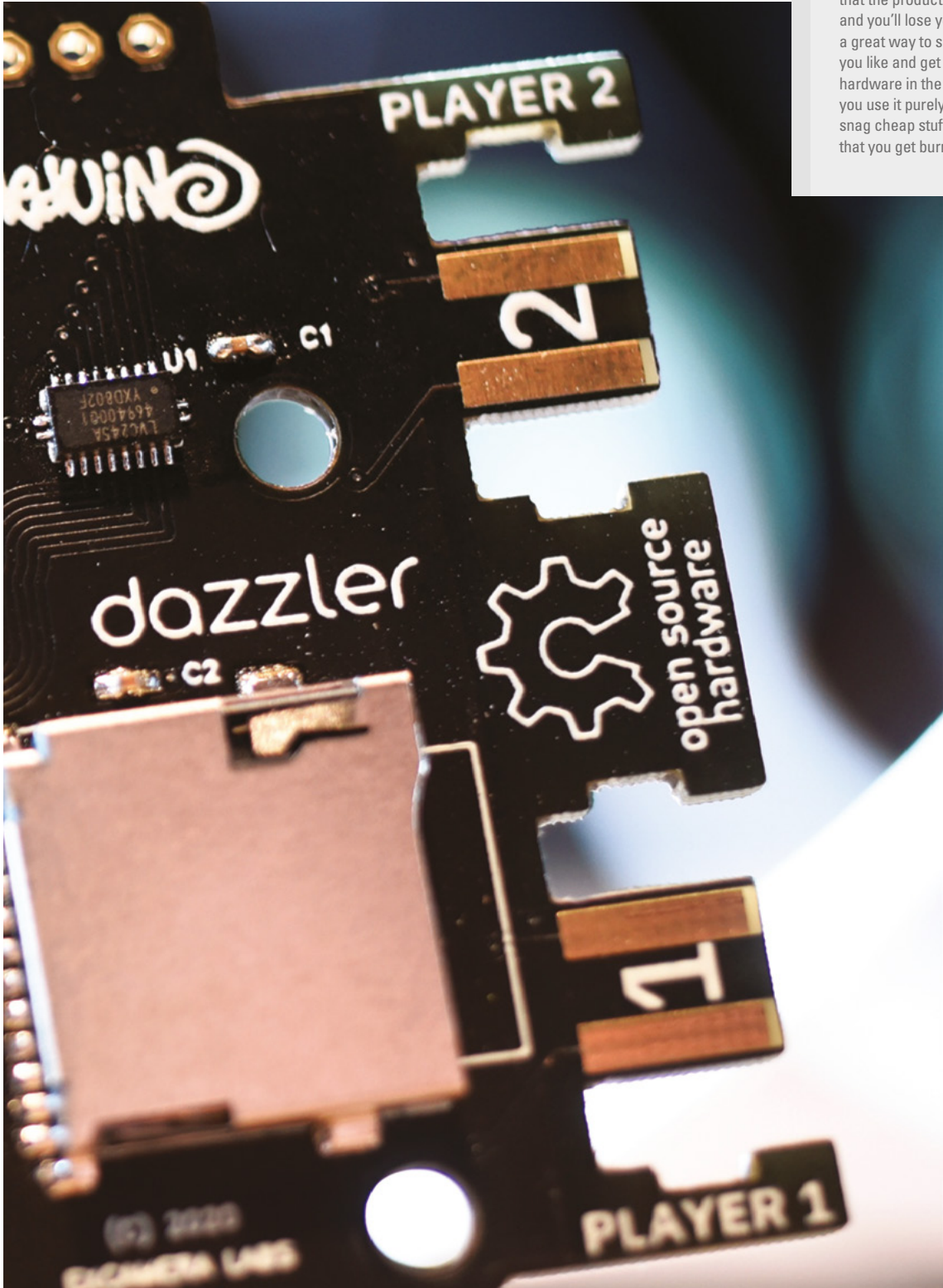
Build a Makerspace for Young People

Join our **free online training course on makerspace design** to get expert advice for setting up a makerspace in your school or community.

Raspberry Pi

The Raspberry Pi Foundation. UK registered charity 1129409

#RPiLearn

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TECHNOLOGY IN YOUR HANDS

LENS
HACK | MAKE | BUILD | CREATE

Uncover the technology that's powering the future

3D PRINTER TIPS & TECHNIQUES

200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 LENS

210
200
190
180
170

3 **D printing is one of the most useful technologies for makers.** It gives us the ability to not only create objects in a reproducible way, but share them with other makers around the world. This ability to share and modify the work of others has lead to a creative boom. However, while the technology has matured significantly in the past decade, the process of going from idea to plastic part is still a little fraught.

In this issue, we take a look at the best tips, tricks, and techniques to get the most out of your 3D printer. Whether it's tinkering with the hardware or optimising your software workflow, whether you're a beginner or seasoned pro, there's always a tip or two you can pick up to help make the process go a little smoother.

Of course, these are only our tips. No doubt you've picked up some brilliant tips yourself, and we'd love to hear them – share them with us on social media, or drop us an email (**hackspace@raspberrypi.org**) and we'll share them with the world in future issues. →

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GETTING THE MOST OUT OF YOUR HARDWARE

Hacks, mods, and picking the perfect printer
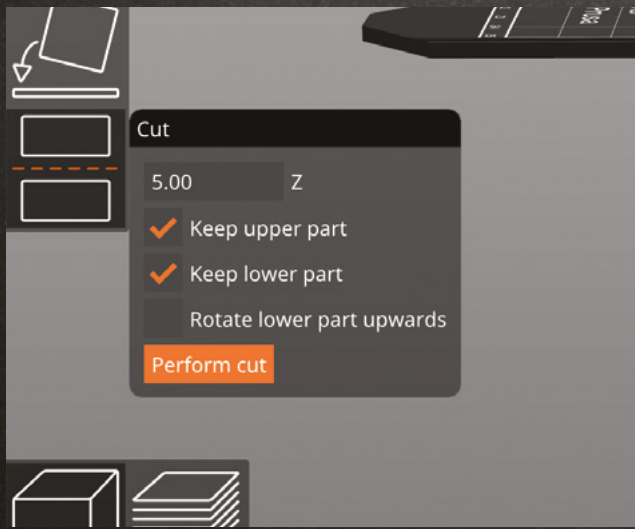
You'll always want a bigger print bed than you have. This is true whatever sized printer you get, but remember that you can print larger objects by splitting them up into smaller parts, and then sticking these parts together after they're printed.

Understand your printer's limits – stringing tests, temperature towers, and overhang tests – these will all help you design and slice your models better.

Perhaps the two biggest things in a 3D printer build that affect the quality are frame stiffness and belt tension. Make sure you do everything you can to get the frame as stiff as possible.

Many 3D printers come as kits, but some kits are much easier to put together than others. Take a look at the build instructions (these should be available online) before purchasing a kit. They should give you an idea about how complex the build is, and you can decide if that's something you want to take on.

Most printers ship with a 0.4 mm nozzle. This is a good general-purpose size, but you can buy smaller nozzles (for more detailed prints) or larger nozzles (for faster prints and larger layer sizes) fairly cheaply.

Dual extruder, or multi-material, printers can produce stunning results, but that's not the only way of getting multiple colours out of a 3D printer. You can switch filaments at a particular point in a print. If you pick the height well, this can allow you to pick out particular features, such as text, in a different colour. You can also use 'rainbow' filament that changes colour along the roll.

Most popular 3D printer models have a healthy community designing after-market parts to improve the user experience. It's always worth a quick look on forums and model-sharing sites to see what other people have come up with. Not all modifications are good modifications, but it's worth seeing what other people are doing.

When purchasing a printer, it's worth looking at what upgrades are available for the future. For example, you may not think automatic bed levelling is worth the investment now, but if you end up becoming a heavy 3D printer user, you may decide it's worth the money.

Lots of printers use open-source firmware. In this, many settings and options are compiled in. If you're looking to tweak your printer, it's worth having a look at the firmware to see what options there are to change it to match the physical modifications you make. →
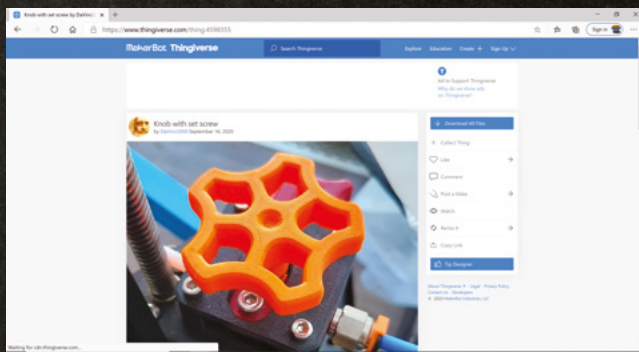
HOT PLASTIC OR RESIN

There are two fundamental technologies behind the majority of 3D printers on the market – those that form a model by building up layers of hot plastic, and those that use UV-curing resin to build up a model by shining light on the liquid.

Hot plastic printers – also known as fused deposition modelling (FDM) or fused filament fabrication (FFF) – usually have a bigger print volume, but lower print quality. Resin printers can produce incredible detail, but usually only for small objects. It's also worth considering the health implications. The resin used is fairly nasty stuff and shouldn't come into contact with your skin. You'll need to wear gloves while handling the print before it's fully washed and cured, which is a separate process requiring separate equipment to printing. It also gives off noxious vapours, so adequate ventilation is a necessity. Don't take these health and safety considerations lightly. Resin printers are much more serious bits of equipment than hot plastic printers. For the right applications, the results can be stunning, but they're messy and toxic.

If you only occasionally need the level of detail resin printers provide, there are many cost-effective options for outsourcing your printing. For example, DirtyPCBs offer resin prints for about US$1 per gram: **hsmag.cc/X06Xa3**.

MASTER DESIGN

Creating useful parts needn't be hard

Think about orientation. One part of your design will be printed flat on the print bed (or a raft), but it doesn't have to be the bottom. When thinking about overhangs, bridges, etc., remember that this is relative to the print orientation, not the actual use.

You don't have to rely on automatically designed supports. If you're going to be printing a lot of an object, or if it's a big print, it may be worth incorporating supports in your design, as this gives you more control over where they're used.
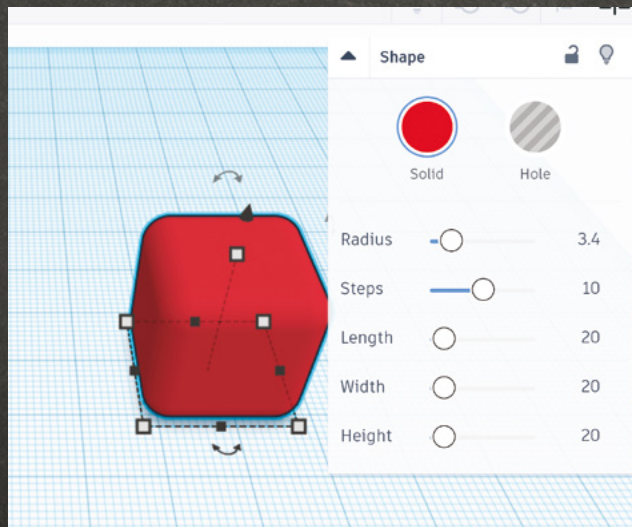
3D printers can struggle with really thin walls. The absolute limit is size of the extrusion, which is slightly more than the nozzle diameter (check your slicer settings for the exact value). Typically, you'll want to have at least two walls for a reliable print, so you shouldn't go thinner than two times the extrusion width. If you have to have thinner walls, you could try a thinner nozzle.

Hard corners can cause problems with designs, so it's often a good idea to soften them with a fillet (rounded corner) or chamfer (a line cutting the single corner into two smaller, gentler corners). There are a few benefits to this. On outside corners, the harsh change in direction can cause wobbles as the extruder's momentum causes it to resist the turn. Sharp corners are also more prone to warp and lift from the build plate. A chamfer or fillet on the inside of the corner can also make the joint stronger.

Just do it! It's easy to be scared of 3D design when you see really impressive designs from other people, but useful designs are often quite simple. Start with the basics and build up from there.

If you have a large design with some bits where precision is necessary (such as holes that need to line up precisely with another object), it might be worth printing just this section of your design to make sure it's accurate before finishing the whole design. Most slicers will let you cut out sections that you don't want to print.
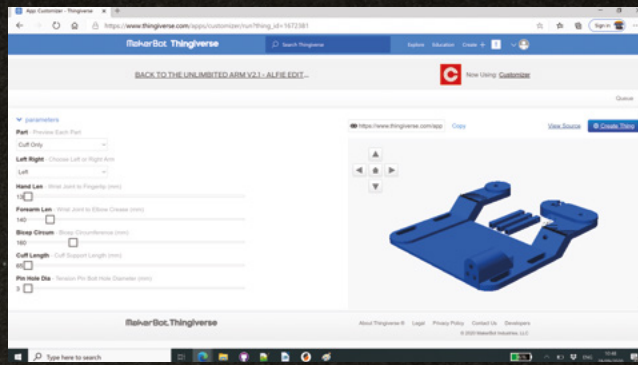
You don't have to design everything from scratch. There are some parametric models that let you tweak aspects of an existing design. The Thingiverse Customizer does this from the web browser, but you can also get models in OpenSCAD and FreeCAD with options built-in.

Don't worry if your design isn't quite right the first time. One advantage of 3D printing is that it's easy, quick, and fairly cheap to make tweaks and test out another revision. It's common to go through several versions before perfecting your design.

If you want parts to fit together, you need to allow a certain tolerance or gap. The exact gap you need will depend on your printer and the particular model, but around 0.2 mm should give a tight fit while 0.4 mm will give a loose fit. You should find a tolerance test on popular model-sharing websites like Thingiverse to see how different gaps feel with your setup.

Share! If you find something useful, then there's a chance that someone else will too. Upload your design to a model-sharing website such as Thingiverse so that other people can benefit. At the very least you'll get a backup of your models, and maybe someone will improve it.

Curves in the X and Y dimensions will have layer lines. Curves in the Z direction won't.
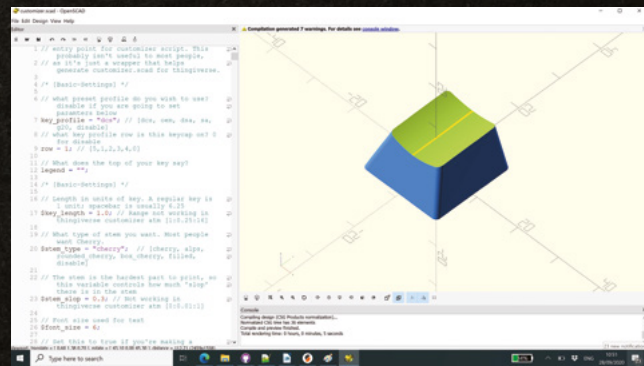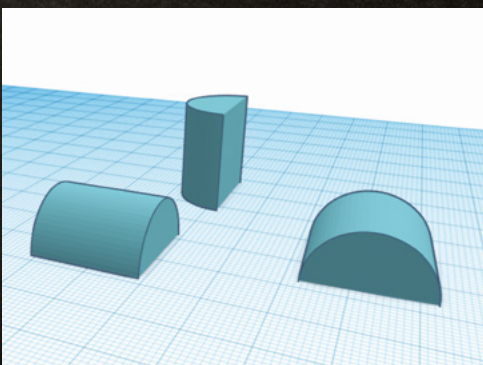
Learning 3D design software takes a significant investment of time. It's worth spending a little time at the start familiarising yourself with the different options so that you know you're picking the right one for you. All the different tools have their quirks, and some will make more sense to you than others. →

PLASTIC PERFECTION

It's the filament that makes your part, so choose it wisely

If you keep a small model printed with each filament you get – perhaps a Benchy – you can then refer back to the look and texture of the filament in the future. Your library of samples will build up over time and give you something to check against if you need a particular look for a project.

Do you have enough filament to finish a print? If you weigh an empty spool from the same filament supplier, then you can compare that weight to the weight of a part-used spool to know how much filament is left. Your slicer should tell you how much filament is needed in grams, so you'll know if you've got enough on the roll to finish the print.

What temperature should you print your filament at? There should be guidelines on the filament you get, but it will vary a little depending on the features of the printer. You can download 'Temperature towers' from model-sharing websites such as Thingiverse that will change the temperature of the print as it goes. By seeing how this affects the print, you can see what the best temperature is for your filament.

Some filaments give off noxious fumes when being printed (particularly ASA and ABS). PLA and PETG don't. If you're printing with these, make sure that you've got adequate ventilation to prevent anyone from breathing in these fumes.

Need a specific colour? Some filament manufacturers will create a custom filament that matches a given colour sample, but it is more expensive than a pre-created colour.
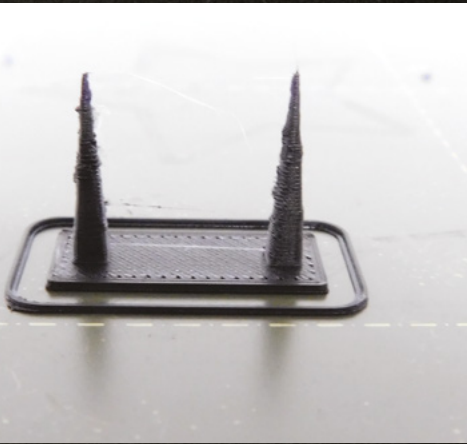
Stringing is a perennial problem in 3D printing. Unfortunately, there's no single thing that causes it. You may want to try lowering the hot end temperature, increasing the fan, or tweaking the Z-hop or retraction settings. Stringing test print designs are available from the usual model-sharing websites and should print quickly (15–20 minutes), and let you test out settings. Try changing one thing at a time until you've minimised the stringing. You won't always eliminate it completely, but a blast with a heat gun once the print's finished should get rid of the remaining strings.

There is no such thing as a universal concept of 'strongest filament'. It depends what you want your part to stand up to. For example, PLA is quite stiff, so it doesn't flex much when you put a load on it, but it doesn't bend much before it breaks. Alternatively, PETG flexes more before it breaks so can be more suitable for mechanical parts.

Many 3D printer filaments gradually absorb water from the air, and as such, they degrade over time. You can reduce this by keeping them in a sealed container with bags of silica gel. How long they'll last will depend a lot on the ambient humidity. You can tell if filament is too moist because it pops and crackles as you print it. You can rejuvenate it by using a dedicated filament dryer, or by popping it in the oven at a VERY low temperature (circa 40 degrees for PLA) or using a dehydrator. If using an oven, bear in mind that not all ovens hold temperature accurately, so you run the risk of fusing all your filament together.

Most plastics aren't UV stable. This means that they'll degrade over time if left in sunlight. The exception to this – as far as 3D printers are concerned – is ASA. This is a great choice if you're printing something that has to live outside or on a windowsill.

Other than PLA, most filaments require a heated bed. However, if your printer doesn't have a heated bed, don't despair. Lots of filament manufacturers produce 'tweaked' versions of PLA that have different properties, such as those that are stronger, more heat-resistant, and flow better.

Many 3D printer suppliers will sell samples of filament. These are a cheap way of trying out different filaments without committing to a full spool.

Not all PLA is the same. Not all PETG is the same. And the same is true for other filament types. If you're having trouble with a tricky model, it may be worth checking how this particular filament works at different temperatures, speeds, and cooling settings.

Bed adhesion is a common problem – some filaments don't stick enough, and some stick too much. Glass beds may require some additions to make sure it works properly – either glue to help it stick, or a surfactant such as window cleaning spray to help it come off. Flexible beds may just require a wipe down with degreaser to help things stick (though don't use too much, or you may struggle to remove some filaments). →

SOFTWARE

From design to control, software runs the show
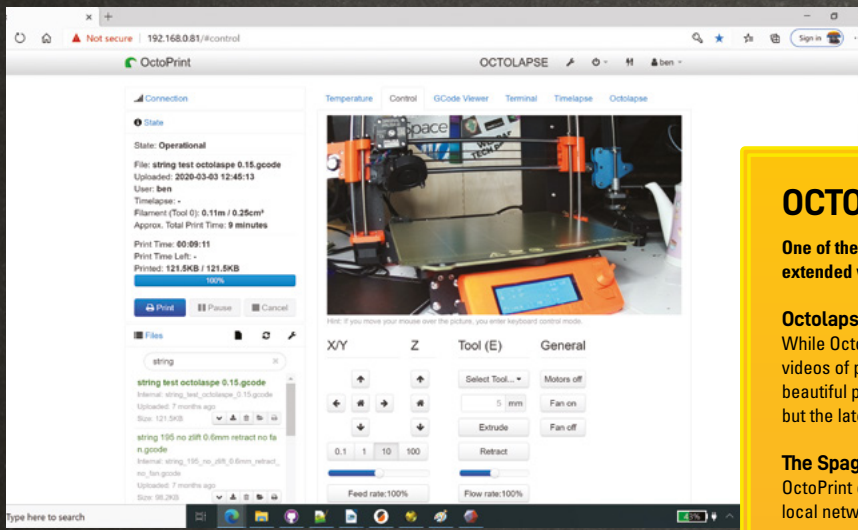
Hands-down, our favourite 3D printer upgrade is adding remote access via OctoPrint. It allows you to start prints and monitor your printer remotely. Remember, though, that 3D printers are a fire risk, so don't leave it running without keeping an eye on it and being close enough to intervene if things start to go wrong. See the box for ways of adding even more functionality.

OCTOPRINT PLUG-INS

One of the great features of OctoPrint is that it can be extended via plug-ins. Here are a few of our favourites:

Octolapse
While OctoPrint does have built-in support for time-lapse videos of prints, Octolapse has far more options for beautiful prints. It used to be quite complicated to set up, but the latest version is far easier.

The Spaghetti Detective
OctoPrint can be controlled by any computer on the same local network as the OctoPrint computer. There are several ways to expand this to make it controllable from outside the local network. The Spaghetti Detective is one such option with the added benefit of using AI to try and detect failed prints automatically. While this is useful, it shouldn't be considered a complete solution, and you still need to monitor your printer manually.

G-code system commands
This lets you create custom G-code commands in your sliced files that will run a specified command on the computer running OctoPrint. This could, for example, trigger the lights on at the start of the print to make sure your Octolapse video is properly illuminated, or email you to let you know that a print has finished.

GPIO Shutdown
This makes it easy to turn off a Raspberry Pi-based OctoPrint machine. Just connect a button between a specified GPIO pin and ground. Pressing this will activate shutdown on the computer.

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MakePrintable is an online tool for fixing and modifying STL files. You upload your file to the web service, and there you can fix things such as the polygon count, wall thickness, holes, and broken meshes. Prices start at US$2 per download.

WHAT DESIGN SOFTWARE?

There's a range of 3D design software available at different feature sets and price points. Here are a few of our favourites:

Tinkercad
This web-based software is easy to get started with. It's quite limited, but you can do basic prints with it. It's a great choice if you don't want to invest too long in learning how to design, and just want to create something simple quickly.
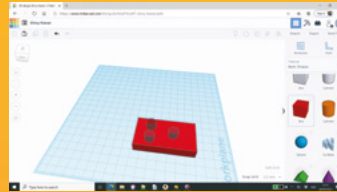
FreeCAD
This powerful open-source 3D design tool is free to use, and a great choice if you're looking to get stuck into the nitty-gritty of 3D

modelling. Look out for a tutorial series in upcoming issues of HackSpace magazine.

OpenSCAD
This works programmatically. Models are defined by scripts that place and transform primitive components to build up the finished design. You'll either love or hate this interface, but it's worth trying, especially if you're a programmer.

Fusion 360
A popular choice for professional designers. It's powerful but does have a bit of a learning curve to get started. It is, however, quite expensive to use. Non-commercial users and students can get a free license, though not all features will be available.

Blender
This is more of an artistic tool than the others here. It's a great option for creating sculpture and other models, rather than mechanical designs.

Meshmixer isn't really 3D design software, but a tool for working with designs to spot problems and make tweaks. We've found it particularly useful when working with resin printers to hollow out objects and ensure that excess resin can drain away. →
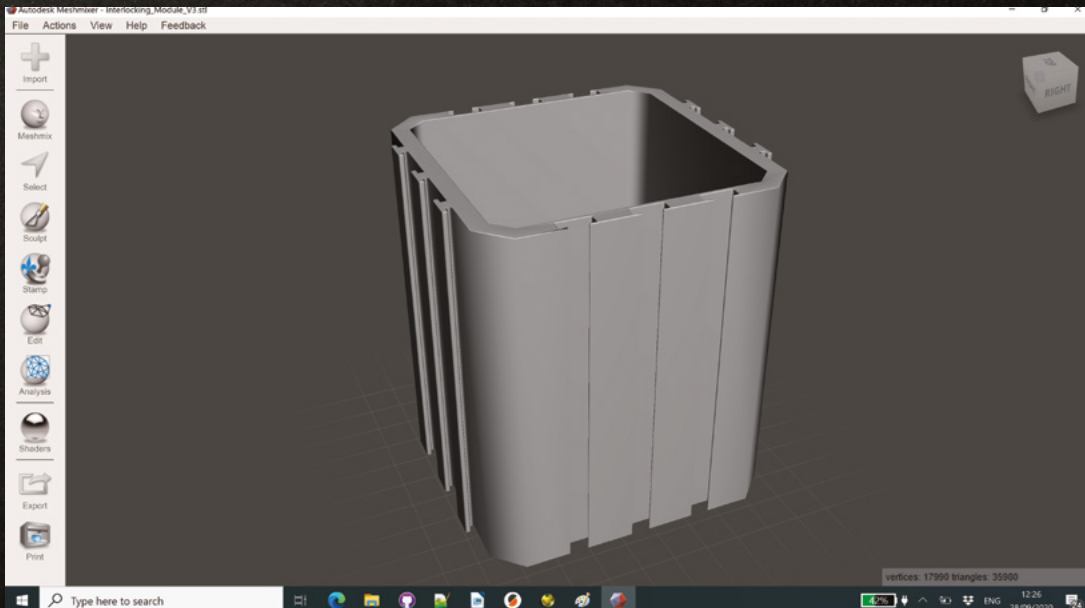
SLICING

Convert your models into perfect prints
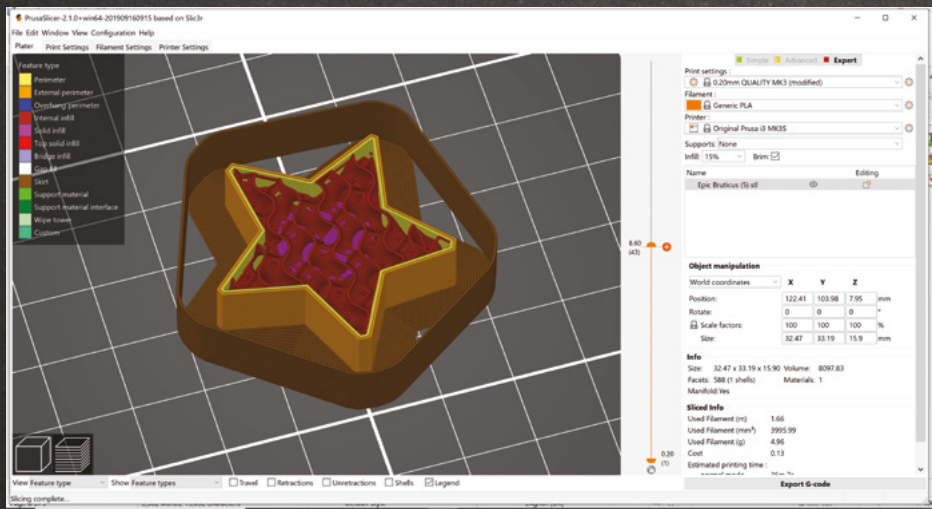
High-temperature filaments like ASA often print better in an enclosure, but if you don't have one, adding a skirt the same height as the object can reduce airflow and help layer adhesion.

It can be tempting to add plenty of infill to make sure your print comes out OK, but you might not need very much. If your part isn't mechanical, 10% may be all you need. Even for parts under stress, 15 or 20% is often enough. Adding more will slow down your print and waste plastic.

If you need a strong print, increasing the number of perimeters can be more effective than increasing the infill percentage.

Cura has some interesting features to try in the experimental setting. We're particularly fond of the 'fuzzy skin' setting for giving textures to 3D prints, but there are many others that create impressive and unusual effects.

There's a range of slicing software available, and (with a few exceptions) you can use any slicer with any printer. It's worth playing with a few different ones to see what suits your workflow the best. Cura, for example, is hugely powerful, but can be a little complex. We mostly use PrusaSlicer in the HackSpace lab which is a little more constrained, but does a great job of just exposing the key features we need.

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C:\Users\ben\Desktop\to print\stylus-with-brim.gcode - Notepad++

Understanding the preview of your sliced part can help identify problems before you've wasted time and filament on a print. Typically, different features are highlighted in different colours. At a basic level, it can be useful to check that overhangs and bridges are supported if needed. You should also be able to see incorrect infill.

Most printers work by taking commands in G-code. Your slicer converts your 3D model into a series of G-code commands. G-code is a text format that you can read yourself. It's not essential to be able to read G-code to use a printer, but there are times when it can help – particularly when trying to do something a little unusual that your slicer may not support such as modifying a temperature tower. You can open a G-code file in any text editor and make changes. Be aware that you may be able to create G-code that damages your printer (such as moving the print head below the print bed), so make sure you're confident of what you're doing before running custom-written G-code.

Supports are a perennial bugbear of 3D printers. Sometimes you can remove the need for them with design tweaks, but for some prints they're inevitable. If you have to print a lot with supports, it's worth investigating other support options such as conical and tree supports (available in the experimental section of Cura).

The first layer sometimes spreads out a little too much as it's pressed into the print bed. This can mean it's slightly larger than other layers. This effect is known as 'elephant's foot'. If it's a problem for your design, you may need to add a chamfer to your design, or enable elephant's foot compensation in your slicer.
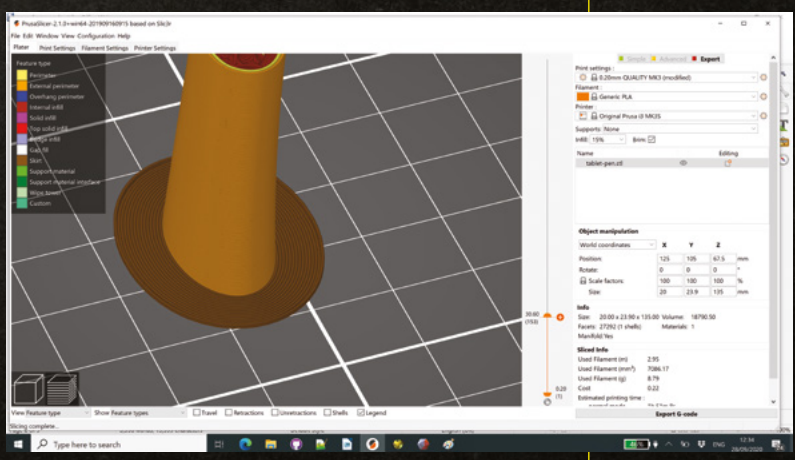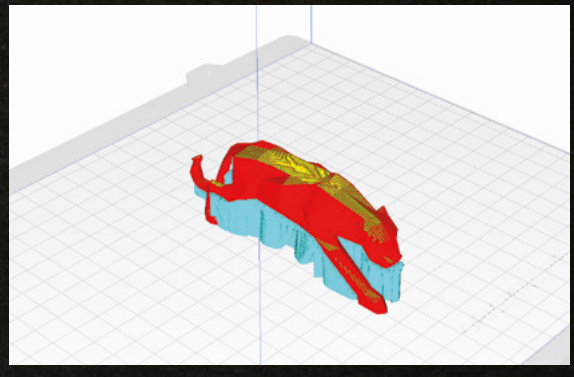
Having trouble getting small parts, or parts with thin protrusions, to stick properly to the bed? Try adding a brim to increase the contact area. ◻

How I Made

'CYSGOD' – A DIY PLYWOOD BOAT

Starting my boatbuilding journey

By **Jo Hinchliffe**

I **wanted to try rowing!** I've got a sit-on-top kayak, and we have a family stand-up paddleboard, but I suddenly got taken by the idea of classic two-oar rowing. I've also wanted to build a boat for a while and, over the years, I had kept returning to a website called Hannu's boatyard – **hvartial.kapsi.fi**. Hannu has a brilliant selection of free boat designs, all built from one, one and a half, or two sheets of plywood.

Built using an adaptation of a method called 'stitch and glue', these designs are affordable and shapely. Although there was a lot of stuff I hadn't ever done before, it seemed feasible. For some of the designs on the website, there are galleries of other people's builds and links to build logs. After perusing those, I had a sense of how much of a challenge it might be for me having never built a boat before. The design I opted for was a 'Micro Auray Punt', which could be built from one sheet

Above ◈
It's fairly easy to handle and carry, and makes it pretty easy to walk into places to launch

of plywood, hopefully by someone with not very refined woodwork skills!

I decided, after lots of research but before building anything, that I was aiming for a functional boat and wouldn't get hung up on building something that was finished to a high standard. I've learnt enough through projects that the first build of most things is full of learning and, no matter how much time you put into it, the second one will be a lot better! An early decision supporting this was that I was going to paint the whole boat, meaning I could cover up any use of filler!

I bought most materials for the boat, but I also scavenged and reused odd bits of timber where possible, again, made easier by the fact I'd decided to paint it all. The costs tend to fall across a few areas: timber about £60, epoxy and cloth/tape around £50, paint £30, plus £10 for some oarlocks. I had some oars, so I didn't have to make any or factor that cost in. Time-wise, I estimate this boat has about 30 hours of work in it over about three weeks, with

If you have ever looked online at plywood boatbuilding, you will probably have seen the term 'stitch and glue'

an hour or two here and there. I'd estimate building a very nicely finished one would be around 50 hours for me – for the better skilled, less!

If you have ever looked online at plywood boatbuilding, you will probably have seen the term 'stitch and glue'. This is where classically component parts of the hull are held together, initially by drilling small holes and then twisting a loop of copper wire through a pair of holes to form a single 'stitch'. Seams are tacked together this way, and then an epoxy seam is built up over the stitches which are finally trimmed back. This boat uses an adaptation of this method using blocks and screws to temporarily hold together the boat's structure. Then, the epoxy resin, thickener, and fibreglass cloth tape create strong reinforced joints on all the seams.

The first part of the build was to mark out the base of the boat and the bow and stern transom, this being the term for the

flat bits on the front and back of the boat. I began by marking a centreline down the entire sheet of 5.5 mm plywood. Marking the transom is easy, and the first real job is to mark (or 'loft' is a term used a lot for this) the curves of the base of the boat. The plans give the co-ordinates of numerous points on the curve from the centreline, and so I used a large roofer's square tool to draw lines out from the centreline at the correct point, and then mark the distances out along those lines. I spent a fair bit of time and care on this, and measured each point multiple times. Once you have all the points marked, you need to then work out how to make the curved shape between the points. I used

a random piece of plastic which is a type of curtain track moulding sold for people fitting curtains into caravans. Essentially, it was a long piece of flexible plastic that could be bent to meet the marked points without breaking. You could also use a very thin piece of wood moulding. I'd seen some people using panel pins just gently tapped into the plywood at the marked points to guide the plastic, but I found if I screwed a couple of screws into the sacrificial floor →
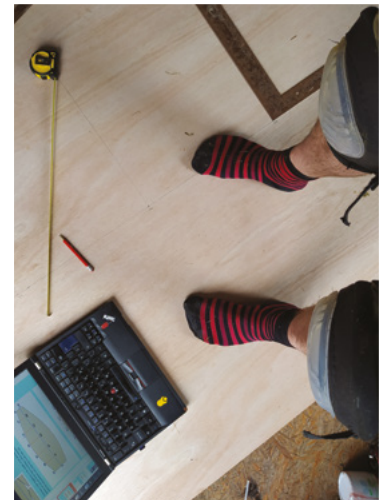
FEATURE

left with four odd-shaped pieces from each side of the sheet. The instructions say to create a butt joint of each pair of these pieces of ply, and reinforce them with fibreglass cloth. Then the idea is that the next day these, now larger pieces, can be marked out and you can cut the side panels from them. I'd also read that a cheap type of cloth tape to use was a kind of tape used for covering the joints in dry-walling. This 50 mm tape is sold quite cheaply and I bought a roll. It was different from fibreglass cloth, but I gave it a go. I laid out the pieces and mixed some epoxy. I realised that the tape required a massive amount of epoxy to 'wet it out', which is the term for when the tape becomes transparent when it contains enough epoxy resin. I managed to get the joint laid up, but I was concerned that the joint would be too thick and that it wouldn't bend too well. That evening I went back to the instructional website and zoomed in on as many pictures which showed the 'dry-wall tape' the author was using. I realised that, in Finland, they have a totally different dry-wall tape that is much more like proper

of the shed, then this could clamp one end of the plastic. Once clamped, I could hold it in position to meet the curve points with a hand and a foot and draw the line. This activity also gave me an idea for a new version of Twister, but themed for makers!

The next job is to cut out what you have just marked. A lot of people tackling this job opt for a jig-saw, but I never seem to get great results from a jig-saw, as they can wander and often cut at a slight angle. I decided I would go for a saw. I used a small

wood-saw for most of the cuts on this boat, and I'd definitely recommend it. Taking my time, I could follow the slowly swooping curves of the base shape, and you get an excellent finish.

FIRST FAILURE
The next part of the build was my first failure! So this design is potentially buildable out of one sheet of plywood. The way this is achieved is that the base and rear transom are cut out of the sheet first, and you are

fibreglass roving cloth! I found an eBay trader that sold 50 mm, 175 gsm fibreglass cloth rolls, and bought a 25-metre roll for the rest of this project's seams! Inspecting the joints I had made with the dodgy dry-wall tape the next day, I realised that, whilst they were functional, they were indeed very thick and, as I had bought a spare sheet of plywood anyway, I decided to cut the sides out from that. This meant the sides looked neater and, when using £22 a sheet plywood, it's not a huge addition to the cost. It also meant I didn't have to wait another day, as I would have had to have epoxied the other side of the butt joint to reinforce them, and then wait another day for it to fully cure.

LOFTY AMBITIONS

Lofting and cutting the sides of the boat is similar to the base, apart from I marked out one side as accurately as I could but then I cut the sheet in half, and clamped the two halves together to carefully cut both sides at once, making sure they matched. With the main parts of the boat cut out, the next part is to get them assembled into shape. The original instructions suggest making a jig which has two long pieces of timber to run

along parallel to the centreline of the boat and then two pieces of 2"×4" placed across each end. The centre of the boat is screwed to the centre of the long pieces using a washer made from an offcut inside the boat. With the centre attached, you can then lift either end of the base and place the 2×4s under each end to begin to pull the base upwards into a curve to form the shape of the base. I had permission to directly screw into the floor of the shed I borrowed to build it in, which worked well, but if I were building another, I would probably use a jig, as then I could mount the entire project on taller work stands/horses to make it easier on my back.

It's then a case of screwing blocks onto the edges of the base and then, in turn, screwing the sides and transom to the blocks. This is quite a challenge, as everything moves and, as you attach more points, the curves change and stuff moves. I think I did the first draft in around an hour and a half, which had lots of gaps and bits that didn't align, but then I did a couple more sessions unscrewing and tweaking and moving blocks about until I was happy with it.

Having got the sides, back, and base to the point I wanted them, I set about mixing

my first batch of epoxy. I've used some different types of epoxy resin – I prefer to have a longer working time before the epoxy hardens, and so I used some DIPOXY-2K-700 epoxy that is billed as an all-purpose epoxy, suitable for casting and laminating and more. I used sawdust to thicken the epoxy when needed, but I think for boat number two I might use something finer →
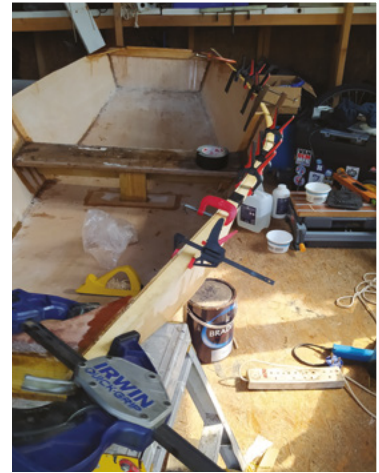
and more consistent in size, as the sawdust meant it was tricky to get a smooth finish at times. Mixing my first thickened batch of epoxy to the consistency of peanut butter, I set about creating some small tack fillet sections between the blocks.

There was then lots of work making the thicker fore transom and internal components for the hull, the triangles in the corners or 'quarter knees', and the seat and supporting structures. Making these parts is tricky, as the hull of the boat is curved in all directions and so everything needs to be shaped in multiple planes. I generally would make parts oversized and then bring them to shape. A handy tool for this was the small Surform plane/rasp. I kept reminding myself that the thickened epoxy was stronger than the timber when cured, and so allowed myself not to worry about gaps that could be filled! Blocks are added as handles, and some blocks are added for the oarlocks – the swivelling oar holding bits I had bought cheaply online.

Once the tack fillets had cured, the boat was strong enough to be unscrewed from the jig/floor, and I could place it on stands to make it easier to work on. Different builders of this design have assembled the boat in slightly different orders. My approach was to finish installing all the internal components, remove the blocks, and finish filleting all the seams with thickened epoxy. I then turned the boat over, and I did the external thickened epoxy seams and the fibreglass cloth reinforcement on the external seams at the same time.

It was the first time I'd really appreciated the curves of the little hull, and it was somehow very pleasing to run your hand over

Flipping the boat over gave me a real sense of satisfaction. It was the first time I'd really appreciated the curves of the little hull, and it was somehow very pleasing to run your hand over. For the outer seams, first of all, cut some of the 50 mm fibreglass cloth into strips. I mixed a large batch of epoxy and then decanted it into two containers to be able to have some thickened and some unthickened. I applied the thickened epoxy as a fillet to all of the outer seams, and then swapped to the unthickened epoxy to begin applying the tape. I applied the

thickened epoxy to make the seam fillet and then added the tape over the top as neatly as I could. Wearing vinyl gloves meant I could use my hands to help poke and prod it into position, and then I applied a little more epoxy over the top to 'wet out' the fibreglass cloth. Once this was all cured, I flipped the boat back over and fibreglass taped all the internal seams, including all the seams around the internal components.

Once all this was cured the next day, I re-flipped the boat over and decided to start bending the 'gunwales'. A gunwale, or a gunnel, is a bent strip of wood that is stuck to the upper edges of the sides. It does two jobs – it acts as a torsional beam and really stiffens the hull up, and also acts to protect the sides from rubbing against stuff when the boat is in use. I'd read numerous approaches to bending the 21 mm square pine timber rails, and I tried a couple of different tactics. I tried pouring boiling water over sections of the timber and using a heat gun as approaches, but the proper way to do this is a simple steam box to steam your wood. I felt that was overkill

to design and build a steam box for the two small gunwales I had to do, but if I build another boat, I'll build a steam box! It took me around two hours of slowly applying more heat from the heat gun and applying hand pressure to get one gunwale made! Sticking the gunwales to the boat is a bit nerve-wracking as, no matter how well you have bent the wood, you are always going to have to add a fair bit of force to get them into position. It's at this point of the build that I also understood why so many boatbuilding websites say you can never have enough clamps! I used every clamp I could find, from quick grip clamps, to hand spring clamps, to engineers' clamps, G-clamps and, as seen in the photos, I even went between the clamps and used some gaffer tape as extra clamping. But having peppered the gunwale with clamps, you can really make sure that there are no gaps.

Plenty of people at this point have painted their Micro Auray Punt and put them on the water, but I reached a decision that I was going to add a layer of fibreglass cloth to cover the entire base of mine. The reason I did this is that where I live in North Wales, most lakes and pools are rocky, with local lake-beds being covered in sharp slate. If you lived somewhere with muddy/grassy

ponds or lakes, or indeed somewhere where you were always going to launch somewhere with a jetty, you probably don't need to do this. I flipped the boat over and added an entire covering of 175 gsm cloth over the base in three sections. This obviously adds a little weight and a little more material cost, but for me, it was worth it. The final job was to give it a quick lick of paint, and I mean quick! My only token gesture to a great-quality finish was I laser-cut some nameplates with the name I had decided upon – 'Cysgod', which is Welsh for 'shade' or 'shadow', and relates to the name of the farm at which I had borrowed a shed. I had some suitable off-the-shelf oars at around the correct length of two metres for this boat and, having added the oarlocks, it was just a case of waiting for a calm day for the maiden voyage!

I was waiting for a calm day with no wind, and when it arrived, we chucked Cysgod on the roof-racks of the car. My version of this boat is probably a little heavier than others with the added fibreglass, but it's pretty easily carried and lifted by one person, and really lightweight if two people lift it. We arrived at the lake, and the first job was to put Cysgod in the water and check for leaking seams. I was extremely pleased

to discover that there didn't appear to be any. However, before I got in and went for a row, I made sure I had a bailer (an empty ice cream container in this instance) and a small towel to mop up any water I brought into the boat so I could keep an eye out. This boat is very buoyant, and when I got in weighing around 100 kg, there was indeed around seven inches of freeboard still above the water, as described on the website. It's extremely light and manoeuvrable in the water and, as a beginner at rowing, I found it took a good 15 minutes of flailing around before I had my strokes even enough for it to mostly go in a straight line. A common modification is to add a short 'skeg' underneath, which is a low-profile, short keel to help the boat track a little better, albeit adding a little more drag. At 190 cm tall, I think I am going to add another small seat section to allow me to slide a little further away from the transom, as I can't quite get my legs flat enough to be out of the way of my rowing. That said, I've had a wonderful couple of trips up and down the local lake. It's incredibly satisfying to be moving through the slight chop of a lake in nice weather in a boat that you have made entirely yourself. I already have plans for the next build! □

Left ◈
As you can see, even with me in weighing around 100 kg the boat sits well on the water

IN THE WORKSHOP: Entering a Hackaday contest

By **Ben Everard**

Turning electronics into art

We've featured circuit sculptures a few times in HackSpace magazine. While there are no hard-and-fast rules, they're typically made from brass rods soldered together. They vary hugely in electrical complexity: some are simple lights, but complex musical creations are also a favourite.

The Hackaday website runs occasional competitions for makers to enter on specific themes. This summer, there's one on circuit sculptures (if you hurry, there's still time to enter: it's open until 10 November).

It's an area I've been playing about in for a little while, with mixed results. In fact, I've been half-way through a project for about nine months, and this was the perfect excuse to finish it off. Like many makers, I'm particularly fond of WS2812B LEDs – sometimes known as NeoPixels. These are addressable LEDs, so there's one data line that can control an almost
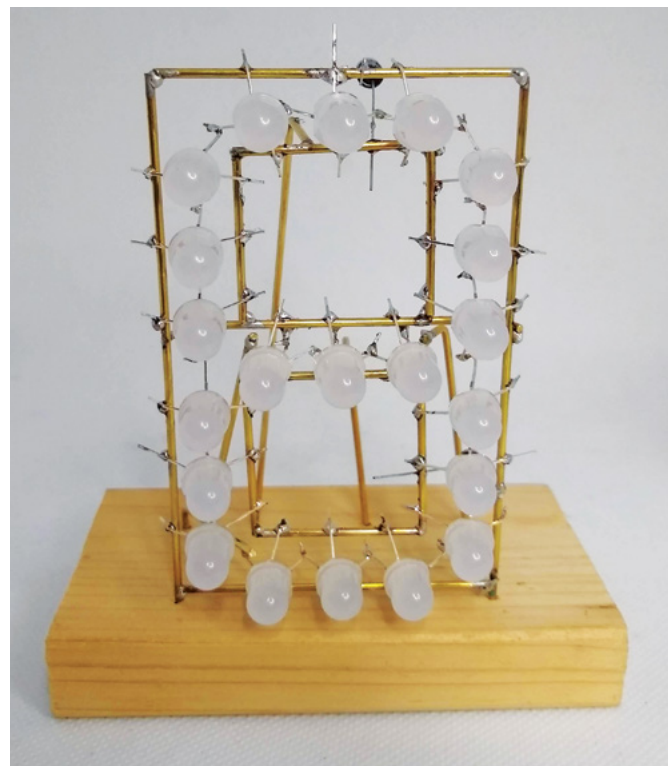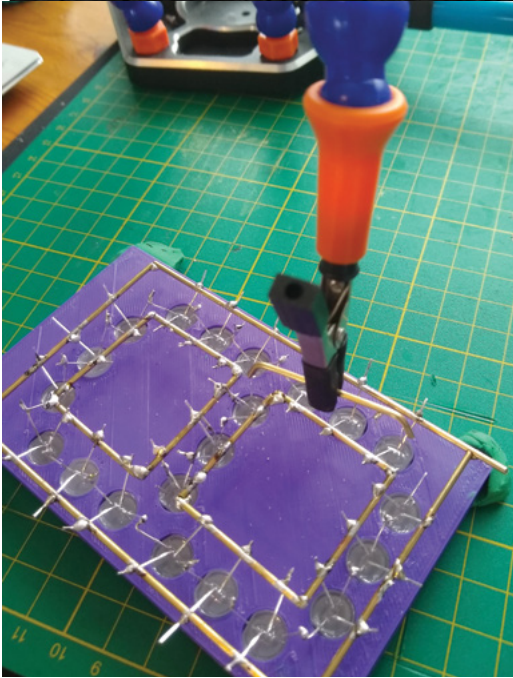
endless series of LEDs. Each LED has a data-in and data-out pin – just connect the data-out of one to the data-in of the next, and you can drive this whole string off one pin on your microcontroller.

WS2812Bs usually come either as surface-mount components or soldered-in arrangements, such as long strips or matrices. However, there is another form: APA106s (not to be confused with APA102, a different chainable LED). These through-hole components look a little like large regular LEDs, but with four legs. They're a great choice for circuit sculptures as they're easy to work with, and you can create impressive lighting effects with very few wires. While circuit sculptures don't have to have LEDs, the reflections on the brass rods give great visual appeal and help show off the structural elements of the project.

The circuit itself is really simple: the outer O of the 8 is ground; the two inner Os are VCC (5 V); and there are also breakouts for the first data-in and the last data-out, so these displays can be chained together. The only extra components needed are capacitors for smoothing the supply – with this many LEDs flicking on and off, fluctuations in the supply voltage can cause problems. I added a couple of 10 µF capacitors between ground and VCC (one in each loop), and that got everything working nicely.

The biggest challenge with building the sculpture is holding everything in place while you solder it. I used a couple of tricks. First, tinning the brass rods before joining them, either to each other or the LEDs, makes it much easier. Building up 2D parts from brass rods (such as the outer and inner loops) can be done easily by taping them in place on a heat-proof mat. Finally,
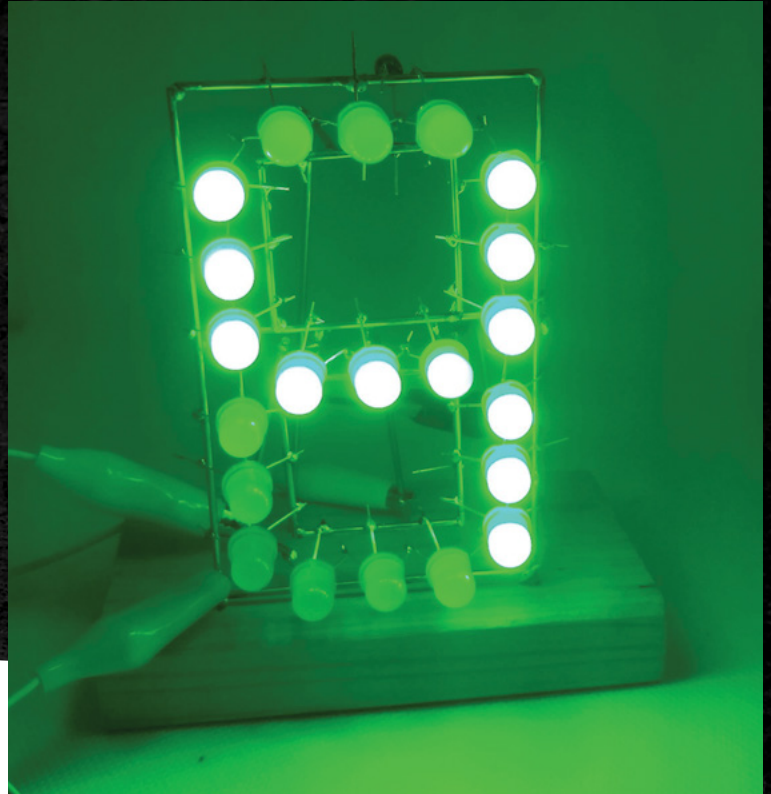
use a jig to hold the LEDs in place while soldering them up. I did try a different approach first – pushing the legs of the LEDs through a piece of paper will hold them in place – but it's not that secure, and it's easy to rip holes that are too large. If you have access to a 3D printer, the jig is a much better approach.

The only slightly tricky bits are adding an extra bar across the middle to supply ground to the three LEDs in the mid-horizontal, and a bar connecting the final LED in the main loop to the first LED in the midline. I used a third hand to hold these in place.

I've tried using a variety of different brass rods over different circuit sculpture projects. You can get brass rods for model-making in a range of thicknesses, but they tend to be expensive. I use brass welding rods which are cheaper, but don't come in the really thin sizes. I have a few thin model-making rods for when a project needs to go into a pin header hole but, most of the time, I use the welding rod.

I then created a Hackaday.io project page and entered it in the contest – you can see my entry at **hsmag.cc/v3nrwl**. You can download the 3D-printable STL file for the jig there, but may find that you need to tweak it up or down a few percent to make it fit.

That's my circuit sculpture, now over to you. What can you come up with to decorate your house or hackspace? If my project hasn't given you enough ideas, you can take a look at the other entries at **hsmag.cc/SL9VmS**. □

Above ⬆
What would you display on your free-form seven segment?

Left ◰
A 3D-printed jig makes everything so much easier

HackSpace magazine meets...

Joshua Zimmerman

Great gadgets for learning STEM skills

We've tried our hand at many an educational project, with mixed success. Instructions are often missing or patchy, which is fine for us because we can use Google – but in a classroom situation, letting kids google independently is a recipe for *Baby Shark* hell.

Science teachers across the USA, and beyond, have reason to be grateful then for the work of Josh Zimmerman and Brown Dog Gadgets (browndoggadgets. com). They've made a name by taking the fiddliness out of science projects, keeping them simple, interesting, and childproof, so teachers can spend more time teaching and less time debugging circuits. →

Brown Dog Gadgets was founded to give teachers more time to teach (this is not a teacher; it's a Lego model made smart and controllable by Brown Dog's Bit board, which combines the worlds of Lego and micro:bit)

HS Hi Josh! First all, who are you and what do you do?

JZ I'm Josh Zimmerman, and I used to be a high school teacher here in Milwaukee, Wisconsin. Around 2011–2012, I started selling projects on the side to help pay the rent, and it snowballed from there. I've been doing this full-time for just over seven years now. There are four of us full time at our office, and we focus on making STEM education products and making resources and materials to put out there for people. Constantly making new resources and material, that's what we're doing right now during the Covid time.

There are two people in our office whose job is full time content creation. One of the big things that separate us from other small STEM education companies is that we're putting out new materials all of the time. Even now with Covid-19, I've seen a lot of other STEM education companies cutting their content creators – they're usually the first people to be let go during a crisis, because it's not a tangible return right away. But we've really doubled down on creating new materials, because it's how we stay in people's minds. Almost all of our business is done in the education market – schools, libraries, museums, after-school programs. Even this summer, we put a few lesson plans together designed for kids to do at home, because we saw the way things were going with the US education market.

HS How are things going at the moment?

JZ The home lesson plans have actually helped us quite a bit. We've got a lot of schools and museums buying things to send home with kids to do those lessons at home. No one's sending home a 3D printer with every kid in the classroom; I joke, but it's true. Over the years, I've watched the big items get sold into schools with lots of fanfare and pizzazz – 'buy this CNC router, buy this MakerBot'. But you can't send that stuff home with kids. Even a Makey Makey is

$50, that's not doable for a school to send 30 of those home with kids. Even the technical support aspect is rough.

But us doing our Paper Circuits lesson plans and activities, it's paper, it's scissors, everyone has those at home. You can easily tech support that by holding it up to a screen – it's tape on paper, so it's easy to see what's going on.

So that's us. It feels like the right kind of thing at the right time. But I know it's been a struggle for a lot of other STEM companies this summer. I talk with quite a few other small business owners, and everyone's having a rough time. We're doing OK.

HS I guess you're just as busy, just in different areas?

JZ Yeah. We do a wide enough range of things. Our big Crazy Circuits sets; our big Classroom set sold really well last year. We're releasing a micro:bit adaptor for the Crazy Circuits system, and we're doing a Kickstarter campaign right now for that, which we're 700% past our goal. But those Classroom sets, those big things, aren't selling right now. However, we are selling tons of little things, in numbers we're not used to – 1000 of this thing to one customer, 800 of something else to another customer. It switched, which we can handle, but it's been an interesting summer.

In the education market here in the US, interesting is not a good word. You want things to be boring. Being a teacher, you want things to be boring and predictable, year to year. If things are interesting, it means you're doing way more work, and you have to replan everything. Teachers right now are overwhelmed with the interesting aspect of replanning all of their lessons for dealing with kids remote learning at home, or being there every other day in some school districts. It's tough, and I really feel for them.

Really we aim for that education market. From a small business perspective, it's predictable, we do consumables. With a Makey Makey or a 3D printer, you're not buying a new →
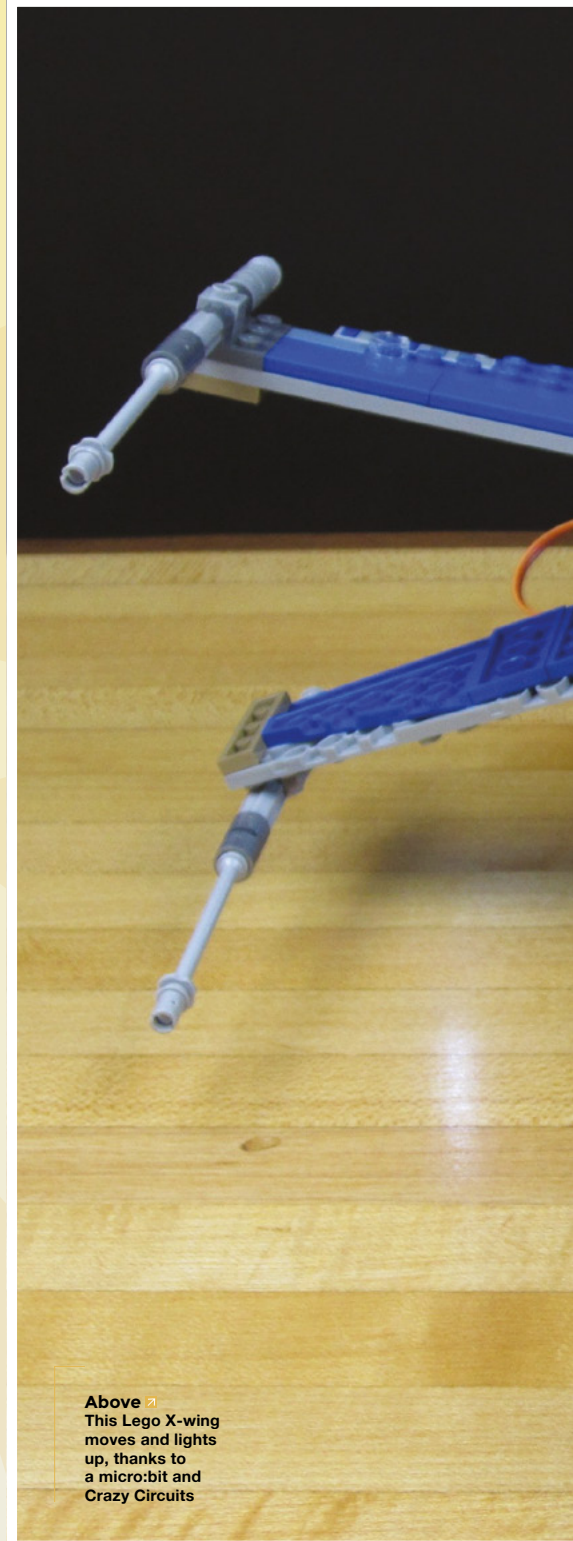
Above ↗
This Lego X-wing moves and lights up, thanks to a micro:bit and Crazy Circuits
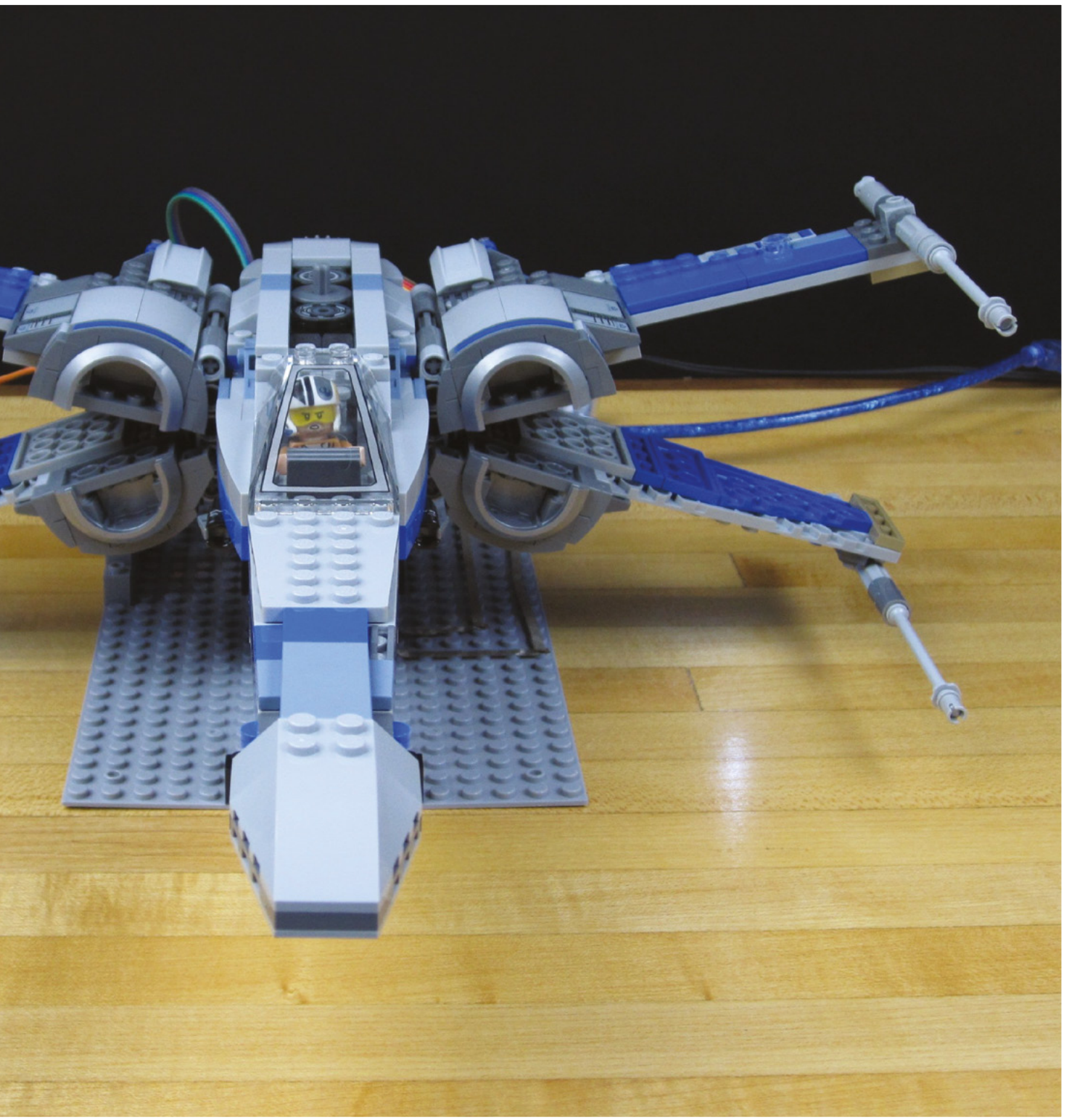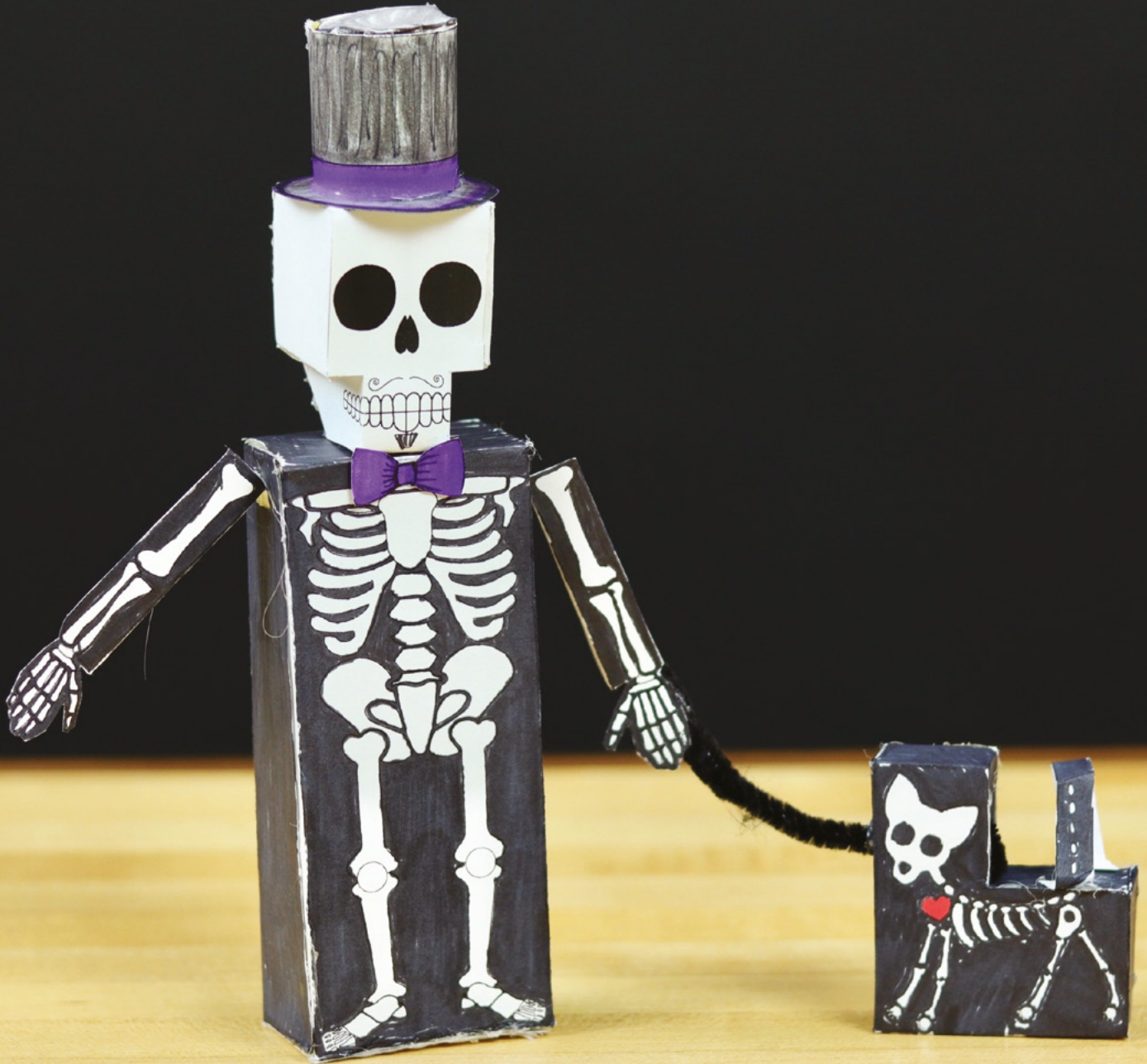
Above ↗
Brown Dog Gadgets makes simple, affordable kits, such as this spooky dog walker

one every year, but with our little things being only a few dollars or less per child, we get repeat sales every year. I'd rather sell crayons than microscopes, because there are always more kids needing crayons every year, but a good microscope should last for 20 years. The ones I had in my classroom were from the mid-1960s. They were tanks, full metal, not a piece of plastic on them. They'll outlive me.

HS **Do you only sell to schools?**

JZ Museum gift shops is a new area for us. But there are also a lot of outreach programs that museums do in their local areas, so we're working with a couple of museums right now who typically have kids come in in their thousands every week to do activities. They can't do that right now, so they're sending the kids home with stuff to do.

Especially in the US, there are tons of outreach programs, summer camps, lots of stuff going on for kids that is run by museums.

HS **How much of your stuff is open-source?**

JZ Pretty much everything. The big thing that we did, especially early on when I was doing the set-up (in my parents' basement of all places), was I started making fairly open-source things like a Bristle Bot or a Solar Cockroach which was our first kit with proper circuits – they're all fairly open-source projects, they've been around for ages, even before they became popularised in the maker movement. I took those projects and made them more classroom-friendly. Nothing annoyed me more as a teacher than seeing a really cool project that no one gave good directions on. 'Hey, I made this cool thing – it's great for kids!' I'm like, how? How do I do that in a way that's kid-friendly, so that the parts are accessible and the build is repeatable? Half the time you see builds that start out with 'hey, I had this old 1954 Cessna, watch as I turn it into a home! You should do it too!' Nobody has

a Cessna in their back-yard. Or nobody has a laser cutter available to them.

That was always frustrating for me, and for my fellow teachers. Even some simpler builds, like buying a bunch of vibrating motors and soldering little wires to them – that is insane! It's bonkers to solder wires onto tiny vibrating motors, and I'm a decent solderer, let alone having fourth- and fifth-graders soldering things.

HS **What do you do to make those projects more classroom-friendly?**

JZ What we've done over time is take those open-source ideas and make them into really nice out-of-the-box projects where we tweak a lot of the parts. Like with the Bristle Bots – we make our own custom toothbrush head for those. Our

> **My goal is that no one should ever give me a customer service phone call**

motors, even our big LEDs that we use in our Paper Circuits kits had built-in resistors in them, because most teachers don't realise that you need a resistor on LEDs, otherwise… I used to get phone calls 'hey, why is the red one on but the blue isn't?" Well, you need resistors, otherwise, it's all going to go through the red LED. Your average teacher or parent at home doesn't know about these things.

You've also got the fact that for a fourth-grader, twisting a resistor onto an LED leg is way too much work for them, especially when it's supposed to be a fun arts and crafts project. So we spent a lot of time tweaking parts. Usually, all the electronics in there have been changed in some minor way to make them more classroom-friendly. One of the biggest

things is that we use a nylon conductive tape in all of our stuff.

Copper foil, which we've all used for things, was readily available, but it sucked. It still sucks, because it's fragile. I've watched kids at Maker Faires and in classrooms just sit there and break piece after piece as they're trying to use it. I had a booth next to a non-profit a couple of years back at Detroit Maker Faire, and I watched a kid go through half a roll of copper tape just trying to go eight to ten inches on a Paper Circuit. It was a poorly designed project, you had to go from point A to point B, and it was really far apart for no good reason. And because the copper foil isn't conductive on both sides, you had to start over again each time you broke a piece. And so we switched to this nylon tape. You have to cut it with scissors, because it's a fabric tape. And it's conductive on the top and bottom, so if you do mess up, you just overlap two pieces and carry on. And you can run it over a component – put a leg down, tape over it, you're good. I give that away non-stop to teachers, because once they try the good stuff, they can't go back to copper tape.

I've been there in the classroom; I know that if you have one minor issue, you're going to get four or five kids out of 30 who are going to get frustrated. And when they get frustrated, they're going to start causing problems. And that snowballs. We want to make sure that everything is so done for parents or teachers that no one should be calling us with issues. My goal is that no one should ever give me a customer service phone call.

We take time and effort tweaking things over and over again. Right now, we're about to change the Arduino shield we use on our dual-axis tracker to a better version. The current one is OK, it works, but we want it to be better.

But in general, because the projects are open-source to begin with, if you have a bunch of electric tape or motors or resistors at home, you're completely
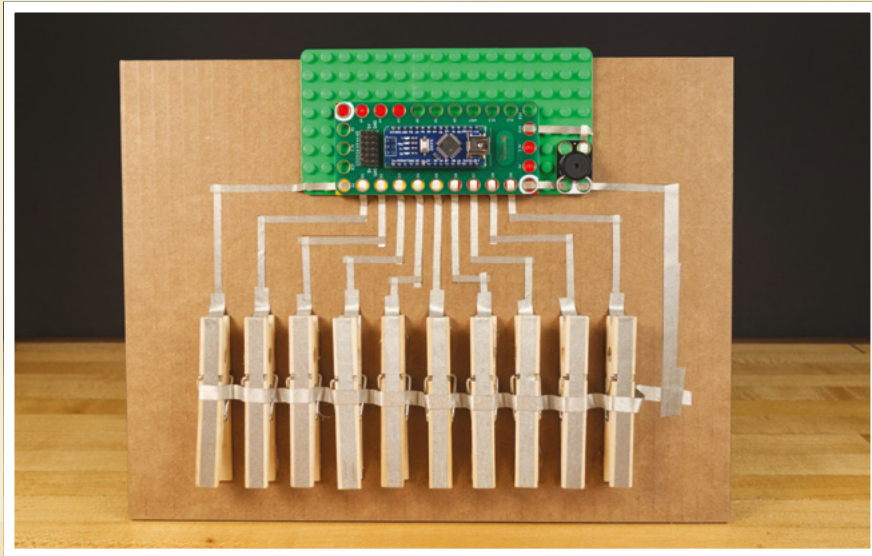
Crazy Circuits is designed to integrate with Lego and cardboard, because that's what classrooms have in abundance already

free to make your own, and use our learning resources to help you. My goal is to create goodwill among teachers and librarians, because word of mouth is so big, and it's free. I'd rather somebody use all their own parts and our directions than try to do something else from scratch. We know our lesson plans are good – they're detailed, they're well laid out. If you want to use your own stuff with our directions, fine. Eventually you'll have seen how good our stuff is, and you'll want to try it out.

HS **There's a lot of lessons, curriculum materials on your website. That's obviously a big part of what you do?**

JZ As a teacher, I would always buy things where I could see the first two pages online. As far as I know, the first two pages are amazing, and the other 98 are blank. I don't know what's in the instruction, because it's behind a paywall. So for us, it makes good sense to show all our cards on the table and let customers make an informed decision – I hate putting things behind a paywall, it's a teacher's pet peeve.

All the big companies out there want to hide their lesson plans, because it prevents teachers from using them without buying. But I don't care. I know that long-term it helps us gain customers, and repeat custom is so big for us, we want to make sure that they

like it and they can do new things as well.

Open-source for us really makes sense. Even with Crazy Circuits, all these little parts on PCBs. The hard part was figuring out the spacing for the Lego holes. Anybody with a brain and experience

> **We know our lesson plans are good – they're detailed, they're well laid out**

designing circuit boards could look at our circuit and be able to replicate it in five minutes. So we thought, screw it: here are all of our references, here's a style guide, here are all of our parts – go for it! If you make ten parts for yourself and solder them up, great, you're not my customer that I really care about.

Maybe you'll say good things about us online, you'll post a blog, you'll link to us on YouTube or somewhere, but most people aren't you – they are teachers

who want to buy something for the classroom. When things are so easy to replicate my thought is, let's just be nice and put it out there anyway. Why be a jerk when it's so simple?

Somebody once sheepishly wrote me an email 'Hey, I used your design for my own thing. Is that cool?' I said 'that's fine, here's a link to our GitHub repository, here are all of our design files. Link to us when you post it somewhere'.

In the education market, things are slow here in the US. The buying cycles for schools takes years. I could have the cure for cancer tomorrow, but no school would buy it for two and a half years, because their buying cycles, their reseller cycles are so long. And that makes it hard for small businesses to get off the ground. You could make an amazing product, but after a year or two, sales will still be horrible.

We're patient. When we put something out there, we let it sit for two years. We promote it, do stuff with it, and if after two and a half years it's not doing anything then we can re-evaluate. It really makes things difficult.

I have a master's in education. I studied history at university. The business side of things has been a revelation, figuring it all out.

HS **How did you go from history to electronics?**

JZ After university, I spent five years teaching English in Japan because I had no idea what to do with my life, so I spent five years avoiding coming to any decision. Then I came back and did a master's in education in the US, and was certified as a teacher here. The problem was, I was teaching full time, and I basically had no social life, because when you're a new teacher, you either teach, or you're working on teaching. So I needed a new hobby. I was a science nerd in high school, and never really did it in college, so I thought I'd pick up electronics. Things had gotten cheap by then; the maker movement was just taking off around 2011–2012, so I started

learning things on my own and posting projects. Part of it, too, was that a lot of things at the time were so badly documented. As a newbie, I could not find anyone to tell me how solar panels worked in an electronic circuit, no matter how hard I searched. There was nothing good out there, and I saw a lot of other people getting frustrated as well. Our first kind of big sales area push, the thing that took us off, was small solar panel projects for the classroom, for the home user.

We used to sell little solar projects that would fit into a (Altoids) mints tin. I think that was our best post over on Instructables, with a million and a half views. Because nobody else was doing it well. Here's a nice write-up, here's some kit you can buy from us, or get it from these other retailers.

It was a hobby that snowballed. It got to the point where I was working two full-time jobs in my last semester of teaching. I'd teach in the daytime, and then go to a horrible office I was renting and work there until late. I was running on empty for the last six months of teaching. I did a Kickstarter campaign for some folding USB solar panels which you can now get for next to nothing on Amazon, but at the time were super-expensive.
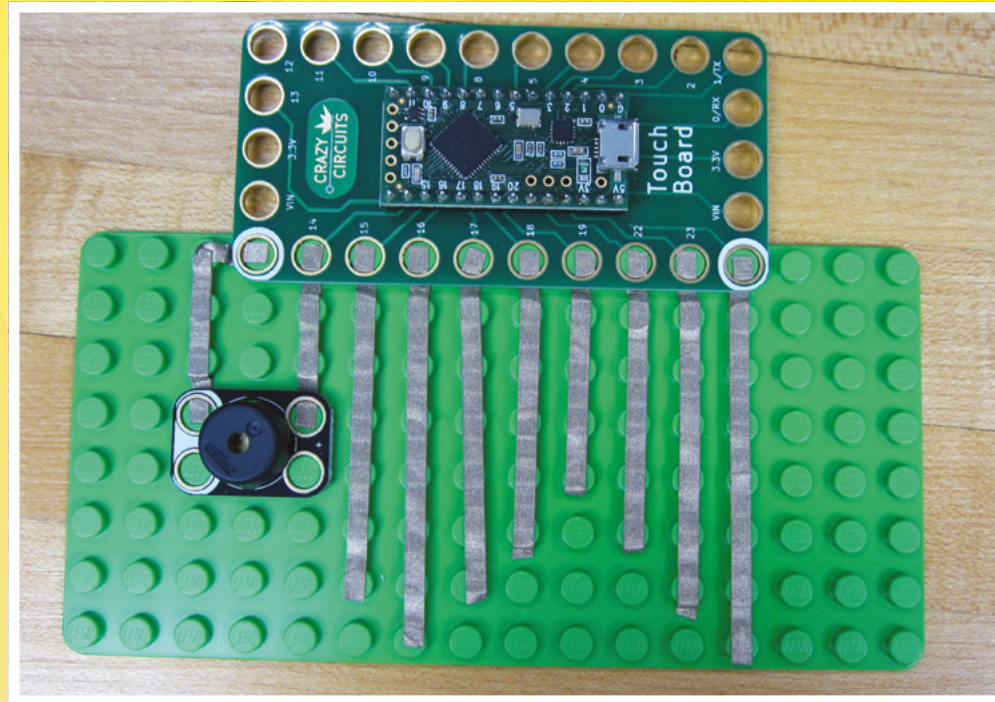
We just happened to have the right things at the right time. We did about $200,000 in Kickstarter money, which gave us enough money to pay me a minimal salary for a year and give the business a go. I was used to making no money. I was earning next to nothing as a teacher, so I was used to living on nothing. But it wasn't planning; I hate to say dumb luck, but it was definitely a case of the right thing at the right time.

We started doing small solar kits that nobody else was doing at a price that worked. In general, we hardly do anything solar at our end – the bigger items just don't sell, because the market has changed. The maker movement has changed; solar panels have got cheaper in general. But we transitioned to other things, such as our Paper Circuits. And we started doing the Crazy Circuit system a couple of years ago because we thought we could improve on the other modular systems out there. You either had Snap Circuits, which are nice kits, but they're aimed at quite a young age range. Eight to twelve is a great age for Snap Circuits, but they then leave that as it's too childish, it's too much of a toy. Being a middle school teacher, I was aiming to create something for those kids who want to try more adult things, but they don't have the skills for it.

Breadboards are hit or miss in a classroom, and jumper wires are a nightmare. There are cool things like Circuit Scribe, and Chibitronics, but they are either the wrong price or not classroom-friendly.

That's what we are up with Crazy Circuits. What kid doesn't like Lego? What adult doesn't love Lego? ▫

FEATURE

IMPROVISER'S
TOOLBOX

YARN

Yarning for creativity

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.

Yarn is one of those things that's just made for makers; you only use it when you have to make something out of it.

In case you haven't heard of it before, yarn is a continuous length of interlocked fibres that's most often used for knitting, sewing, and crocheting and on an industrial level, for producing fabrics. These days, yarn is made from a variety of different fibres, including both natural and synthetic fibres. Cotton and synthetic polyester are the two most commonly used fibres. Also common are animal fibres, such as wool that comes from sheep, cashmere from goats, and silk from insects.

Besides the type of fibre, the other yarn qualities you'll be interacting with most often include their weight and colour. Yarn weights range from very fine lace (usually denoted by the number 1), all the way

by weight, in ounces or grams. The actual length of the yarn in a ball or skein varies due to the weight of the fibre and the thickness of the strand.

Though we have long since moved on from the age of the homespun, knitting yarn is still one of the favourite pastimes that's practised across cultures, and countries. Funnily though, since knitting yarns decay with time, archaeologists haven't been able to determine how long this art form has been around. They've found knitting needle-like sharpened sticks at several digging sites, but these could just have been tools for some other purpose.

That said, most historians believe that the craft originated in the Middle East, and later made its way to Europe sometime during the Middle Ages between the 5th and the 15th century. The word knitting, though, made its debut in the English language in the 1300s.

Did you know that David Babcock holds the Guinness World Record for completing the Kansas City Marathon in 5 hours, 48 minutes, 27 seconds? If you think you can do better, remember that David ran the race while knitting a scarf that measured 3.70 metres, or just over 12 feet long, when he crossed the finish line!

For those who wouldn't be able to do much with yarn even when sat on the sofa, here are some projects with yarn that don't involve any knitting or crocheting.

> **"YARN IS MADE FROM A VARIETY OF DIFFERENT FIBRES, INCLUDING BOTH NATURAL AND SYNTHETIC FIBRES"**

to the number 6 for thick, bulky yarns. Yarn can be used undyed, but it is more common to find them coloured with natural or artificial dyes. Yarn quantities for knitting and crafts are usually measured and sold

WALL ART

A self-proclaimed multi-crafter, Fern aspires to try as many crafts as possible, and it's no surprise that we've featured her creativity earlier as well (back in issue 12). Here, she combines her two passions: simple and bold designs and yarns to create mini artworks on stretched canvases. Her idea is pretty straightforward and quite fun to execute with kids.

Start by pencilling the outlines of your selected designs onto the canvas. For her tutorial, she's used a Mondrian-inspired colour block design, a wave, and the sun. She's used 5″ × 7″ canvases, but you

"She's used a Mondrian-inspired colour block design, a wave, and the sun"

can use larger ones if you prefer; just remember that they'll need more time and more yarn. After drawing the outline, fill in the segments with acrylic paints that are similar to the yarn colour that you'll be adding on top. Once it's dry, use a paintbrush to apply some PVA glue on one part of the design, and then add lengths of coloured yarn over it. While you can add individual lengths of yarn, Fern suggests using one long length and just looping it around. Cut off the excess yarn, and you're done. The process is a lot more involved than it sounds, and Fern's detailed it nicely in her tutorial for all the three designs. →

Project Maker
Fern

Project Link
hsmag.cc/4uz0Gl

SMALL BASKETS

Project Maker
JAMIE

Project Link
hsmag.cc/6nIaxX

—

Jamie, too, was inspired by an idea she saw in a magazine. The kids can make the baskets on their own. Turn a bowl upside down and drape a sheet of plastic wrap over it. Jamie and her kids then used quite a lot of 17″ long strips of yarn. The length actually depends on the size of the bowl, but the longer the better, as they'll help create a sturdier basket. Jamie then suggests soaking the yarn strips in a shallow dish of glue. If the glue is too thick, you can add a little water to it to make it more workable. After soaking the strings for a little while, pull them out and drape them over the plastic bowl. Wrap them from side to side and use some to go around the body. Dry the completely covered bowl overnight before you remove it and peel the plastic from the string to get the baskets.

Right ⬥
The project is a useful outlet for any leftover yarn from any of the previous projects

TOY BIRD

Project Maker
MUHAIMINAH
FAIZ

Project Link
hsmag.cc/6oUjRv

A craftaholic always on the lookout for unique craft ideas, Muhaiminah ran across a picture of a bird made of yarn on Pinterest. She was able to replicate the design on her first attempt, and has detailed the process in her Instructable. Using three pieces of card-stock paper of different sizes, she created a group of different coloured yarn strands. The next step is to fold the three groups of yarn over each other to create the torso of the bird. Muhaiminah has done a great job of explaining and illustrating the folds. The rest of the process involves fabricating and connecting the wings made out of paper, a beak made with orange-coloured card-stock paper, a pair of twisted craft wires for the feet, and other features to this yarn torso. Once you've mastered the fold, Muhaiminah suggests you use different coloured yarns to create birds with unique patterns.

Left ◈
You can create these birds with kids, and they make for nice, lightweight Christmas ornaments

GLASSES CASE

Project Maker
CATHY
VILLAMAR

Project Link
hsmag.cc/Ngd0pT

H ere's another canvas-based project that's more utilitarian. Cathy shows you how to transform a simple plastic canvas into a retro case for your glasses. The plastic canvas allows for some interesting and cool patterns and, at the same time, is sturdy enough to hold lightweight objects like glasses.

After procuring the plastic canvas, measure it according to your glasses, before cutting it to size. Cathy then used yarns of four colours and decided to go along with a simple staggered zigzag pattern. She tied the yarn to four different needles and then needlepointed a couple of rows each with the four colours. Cathy started at the bottom left corner and went up diagonally and across, since this worked best for the pattern she selected. If you decide on another pattern, you might find it easier to work across from one side to the other. Once you've patterned the entire canvas, Cathy suggests you use one of the colours to sew along the top edge. She suggests sewing two stitches in each hole to keep any of the plastic canvas from showing through. When you're done, fold the canvas in half and sew two sides and leave one open to slide in your glasses. ◻

Left ◈
Expert weavers can choose a different design or repurpose the case to hold something else, such as a mobile phone or trinkets

FORGE

HACK | MAKE | BUILD | CREATE

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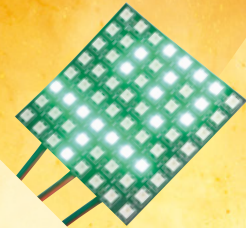
CircuitPython:
NeoPixel displays

Add text and other images to your LED matrices

Ben Everard

🐦 @ben_everard

Ben has spent an unhealthy amount of time looking at blinking lights this month.

W S2812B LEDs (or NeoPixels, as they're commonly known) are LEDs that can light up in any colour. Really, they're three LEDs (one red, one green, and one blue) in a single package. Also in there is a tiny processor that supports a simple networking protocol that lets you control lots of NeoPixels from a single pin on your microcontroller.

CircuitPython has great support for NeoPixels using the neopixel module. Using this, you can turn individual LEDs on and off and change their colour easily, but in this article, we're going to look at something a little more complex – LED matrices. These are rectangular grids of LEDs that can be used to display lights, shapes, text, and more. You can build your own tiny Times Square. To make it simple

to draw images and text on these displays, we can use the pixel_framebuf module. In this article, we'll be using an 8×8 matrix, but you can use larger ones. However, the time it takes to update the screen will take longer for larger matrices, and if you go too big, you might run out of RAM.

First, let's set up our CircuitPython device. It's best to update to the latest version of CircuitPython (5.3), and get the latest set of libraries. You can download both of these from **circuitpython.org**.

Once your device is set up with the latest firmware, we can get coding. As always with CircuitPython, the main file is **code.py** on the device, and we'll be editing it with the Mu editor.

The first bit is to set up our NeoPixels. There's nothing fancy here: you just need to tell the library how many LEDs you have and which pin they are attached to.

```python
import board
import neopixel
from adafruit_pixel_framebuf import
PixelFramebuffer
import time

pixel_pin = board.A1
pixel_width = 8
pixel_height = 8

pixels = neopixel.NeoPixel(
    pixel_pin,
    pixel_width * pixel_height,
    brightness=0.1,
    auto_write=False,
)
```

The next thing we need to do is set up the pixel_framebuf. This is short for frame buffer, which is a common way of driving screens. Essentially, it means that you have a bit of RAM that stores the values of each pixel that can be periodically written out. We don't need to worry too much about this
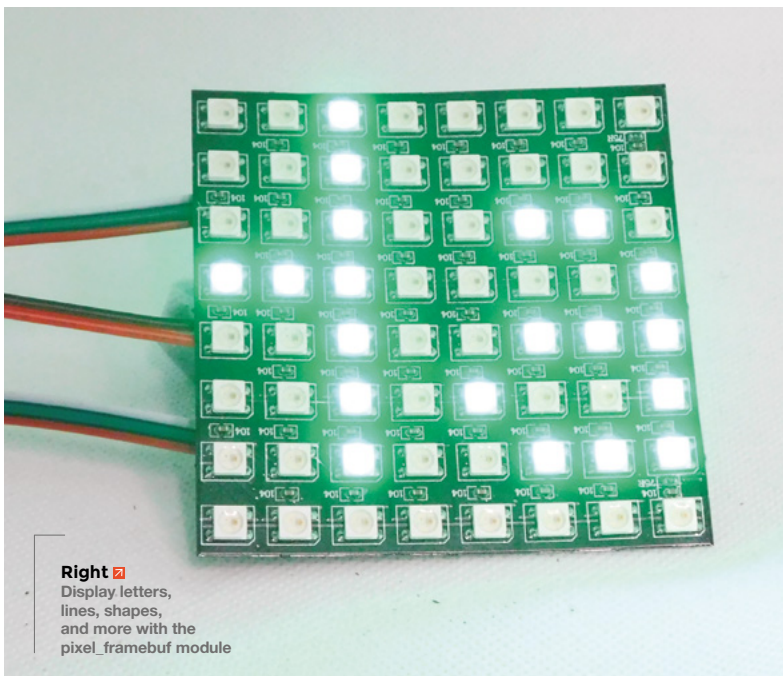
Right ↗
Display letters, lines, shapes, and more with the pixel_framebuf module

behind-the-scenes setup with this library, as it gives us some methods for creating items on the screen in different ways.

There are a few different ways that LED matrices can be set up. The most common difference is between 'alternating' or 'not alternating'. This basically means that, on an 8×8 matrix, for example, the pixels 0 to 7 are along the bottom, then pixel 8 is above 7 (thus making an 'alternating' or zigzag pattern) or above the 0. By default, alternating is enabled, but set it to false as a key word argument if your display isn't. You may be able to tell this by looking at traces on your matrix PCB, or you may just have to do a bit of trial and error to see what works. The other major difference is whether the first pixel is in the bottom left or the bottom right. If it's bottom right (like ours), you'll have to flip the x axis.

```
pixel_framebuf = PixelFramebuffer(
    pixels,
    pixel_width,
    pixel_height,
    reverse_x=True,
)
```

Now we've got everything set up, let's take a look at how to put some designs on the screen. There are a few ways of drawing on – to get a complete picture, you can take a look at the documentation here: **hsmag.cc/YeaAU0**. This is for framebuf, not pixel_framebuf, but this is the parent class of the pixel one, so you can use all these methods.

We'll get everything started using some text. Obviously, you can't fit much on an 8×8 matrix, but there is a font that displays each character as an 8×5 grid. We can use this font and scroll the text across the screen to make a readable display. The code for this is:

```
while True:
    for i in range(0, -6*14, -1):
```

DRAWING IMAGES

CircuitPython is mostly used on microcontrollers, but it can also be used on general-purpose computers such as Raspberry Pi. On these more powerful devices, it's run as a layer on top of regular Python (via the Blinka library).

This gives you access to a range of powerful tools that don't usually run on CircuitPython, such as the Pillow image library. With this, you can display image files in NeoPixels. For details, take a look at **hsmag.cc/jRZm2v**.

```
        pixel_framebuf.fill(0x000000)
        pixel_framebuf.text("HackSpace Mag", i,
0, 0x00ff00)
        pixel_framebuf.display()
        time.sleep(0.1)
```

You'll also need to save the **font8x5.bin** file in the root of your CircuitPython device. You can download this from **hsmag.cc/jHw755**.

Before you can run this, you'll also need to connect your matrix. Your NeoPixel string will have three connections – power, ground, and signal. Connect the power to 5 V, ground to ground, and signal (or data-in) to any of the pins on your microcontroller. Technically, this is a little out of spec for the NeoPixels, since they need a signal that's at least 0.8 times the power in, but usually, it works fine. If you have problems, it can be worth adding a signal diode (which typically have a 0.7 V drop) to the power line.

That's the basics of using the pixel_framebuf module. With it, you can create interesting and powerful graphics, but how you choose to do that is up to you. □

Below ◈
We did this on a Circuit Playground Bluefruit, but it should work on any CircuitPython-enabled microcontroller

TUTORIAL ━━━━━━━━━━━━━━━━━━━━━━━━━━━━
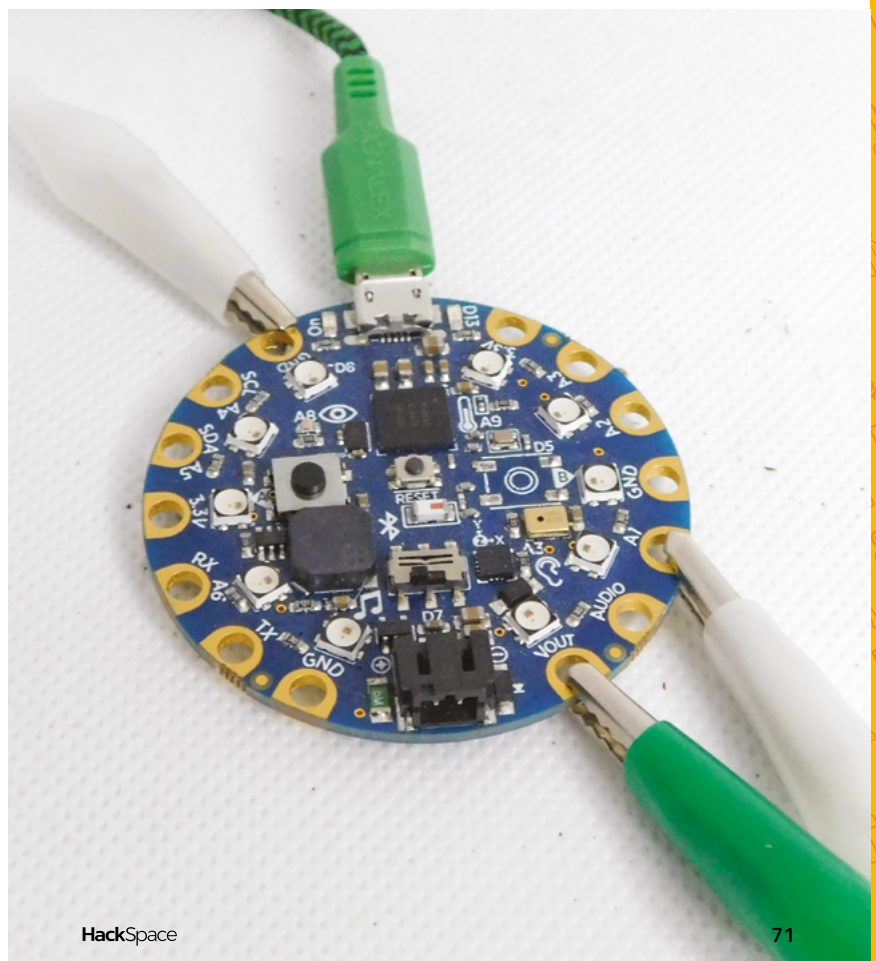
3D printing with conductive filaments

Make your 3D prints electric

Ben Everard

🐦 @ben_everard

Ben's house is slowly being taken over by 3D printers. He plans to solve this by printing an extension, once he gets enough printers.

When thinking of conductive materials, you usually think of metals that have very low resistance. A wire in a circuit typically has a resistance of less than one ohm, meaning that – for most purposes – it has negligible effect on the current flowing through it. Plastic, on the other hand, is famously an insulator. We often make project boxes out of plastic to stop anything accidentally conducting electricity between two points on a circuit that we don't want power conducted between. Conductive 3D printer filament is a half-way house between these two extremes. It's a plastic (often PLA, but there are other options) with a little something (often carbon) added to allow electricity to flow, but it's not very good at letting electricity flow. It's hard to give exact values of what sort of resistances you should expect, as this varies depending on the manufacturer and the size of the thing you're conducting through. However, to give you an idea of what to expect, the 1.75 mm filament on test had about 300 ohms resistance per centimetre. Remember that this is based on the 1.75 mm diameter as it is on the spool – once it's printed, it will have a lower resistance if the trace is thicker than this or higher if it's thinner. This is a fairly substantial resistance. There's a wide range of filaments available with different properties. Some of

Below ◈
3D-print your own ergonomic stylus with conductive filament

> **Typical conductive PLA still isn't cheap, and you** shouldn't expect much change from £100 per kilo

the more expensive graphene filaments do claim a much lower resistance, but at prices approaching £1000 per kilo, these are very specialist materials. Typical conductive PLA still isn't cheap, and you shouldn't expect much change from £100 per kilo (though they are often sold in small spools).

You can make circuits with a material with resistance as high as conductive PLA, but not many. Lighting an LED is possible, as long as you keep the connections short and thick. If you try to do anything much more complex, then you're likely to struggle.

However, building circuits isn't the only reason we use conductors.

Many bits of technology around today – from mobile phones to microcontroller dev boards – can sense the amount of capacitance and they use this to detect if a person is touching an object or not. This conductive filament is conductive enough to allow these sensors to 'read through' 3D-printed objects.

For example, if you 3D-print a stylus shape in regular plastic and poke your phone with it, it won't do anything, but if you use conductive filament, then you can use it to interact with your digital device. If you 3D-print a structure out of conductive PLA and connect this structure to a capacitive sensing pin on your microcontroller, then the whole structure can become touch-sensitive. Perhaps more interestingly, if you have a dual-extrusion printer, and use both conductive PLA and regular PLA, you can connect multiple capacitive sensors up to a single object and create interesting and unique musical interfaces.

TOUCHSCREENS

One thing to be aware of, if interacting with touchscreens, is that stiff plastics such as PLA struggle to work with a touchscreen. Because there's little deflection in the plastic, unless you're very careful to hit the screen at the correct angle, you often hit it with a corner of the 3D-printed model, and this doesn't always give enough contact to register as a touch. With flexible filaments, the plastic should deflect slightly and give a larger touch area, though the exact effectiveness will depend on the combination of the touchscreen, the 3D model, and the filament. ☐

PRINT SETTINGS

Conductive materials generally print in a similar way to the underlying material. Conductive PLA should print on a PLA setting, and similarly for other base plastics. Given the price of it, it's probably worth printing a small test piece before committing to a large build.

In general, plastics with additives result in weaker prints, but the graphene-enhanced conductive filament is an exception to this. The fibrous nature of graphene can mean your parts will end up being much stronger than regular filament (this only holds for the more expensive graphene filament, not regular conductive filament). That said, we wouldn't want to risk breaking parts that are that expensive to print, so we wouldn't recommend pushing it too far.

Talk to your Raspberry Pi

Add voice commands to your projects with a Raspberry Pi 4 and a microphone
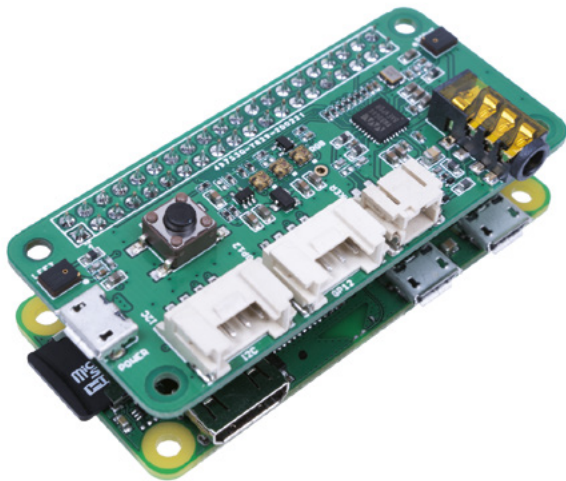
PJ Evans

🐦 @mrpjevans

PJ Evans is a developer and wrangler of the Milton Keynes Raspberry Jam. He runs a LoRa gateway, which is probably the nearest he'll get to his own radio breakfast show.

t's amazing how we've come from everything being keyboard-based to so much voice control in our lives. Siri, Alexa, and Cortana are everywhere and happy to answer questions, play you music, or help automate your household. For the keen maker, these offerings may not be ideal for augmenting their latest project as they are closed systems. The good news is, with a bit of help from Google, you can add voice recognition to your project and have complete control over what happens. You just need a Raspberry Pi 4, a speaker array, and a Google account to get started.

SET UP YOUR MICROPHONE

For a home assistant device, being able to hear you clearly is an essential. Many microphones are either too low-quality for the task, or are unidirectional: they only hear well in one direction. To the rescue comes Seeed's ReSpeaker, an array of four microphones with some clever digital processing to provide the kind of listening capability normally found

on an Amazon Echo device or Google Assistant. It's also in a convenient HAT form factor, and comes with a ring of twelve RGB LEDs, so you can add visual effects too. Start with a Raspberry Pi OS Lite installation, and follow the instructions at **respeaker.io/4_mic_array** to get your ReSpeaker ready for use.

INSTALL SNOWBOY

You'll see later on that we can add the power of Google's speech-to-text API by streaming audio over the internet. However, we don't want to be doing that all the time. Snowboy is an offline 'hotword' detector. We can have Snowboy running all the time, and when your choice of word is 'heard', we switch to Google's system for accurate processing. Snowboy can only handle a few words, so we only use it for the 'trigger' words. It's not the friendliest of installations so, to get you up and running, we've provided step-by-step instructions at **hsmag.cc/5X0cph**.

CREATE YOUR OWN HOTWORD

As we've just mentioned, we can have a hotword (or trigger word) to activate full speech recognition so we can stay offline. To do this, Snowboy must be trained to understand the word chosen. The code that describes the word (and specifically your pronunciation

QUICK TIP

You can use a 'regular' USB microphone if you prefer, and the results can be very good.

Above ↗
ReSpeaker can use its multiple mics to detect distance and direction

Right ⬥
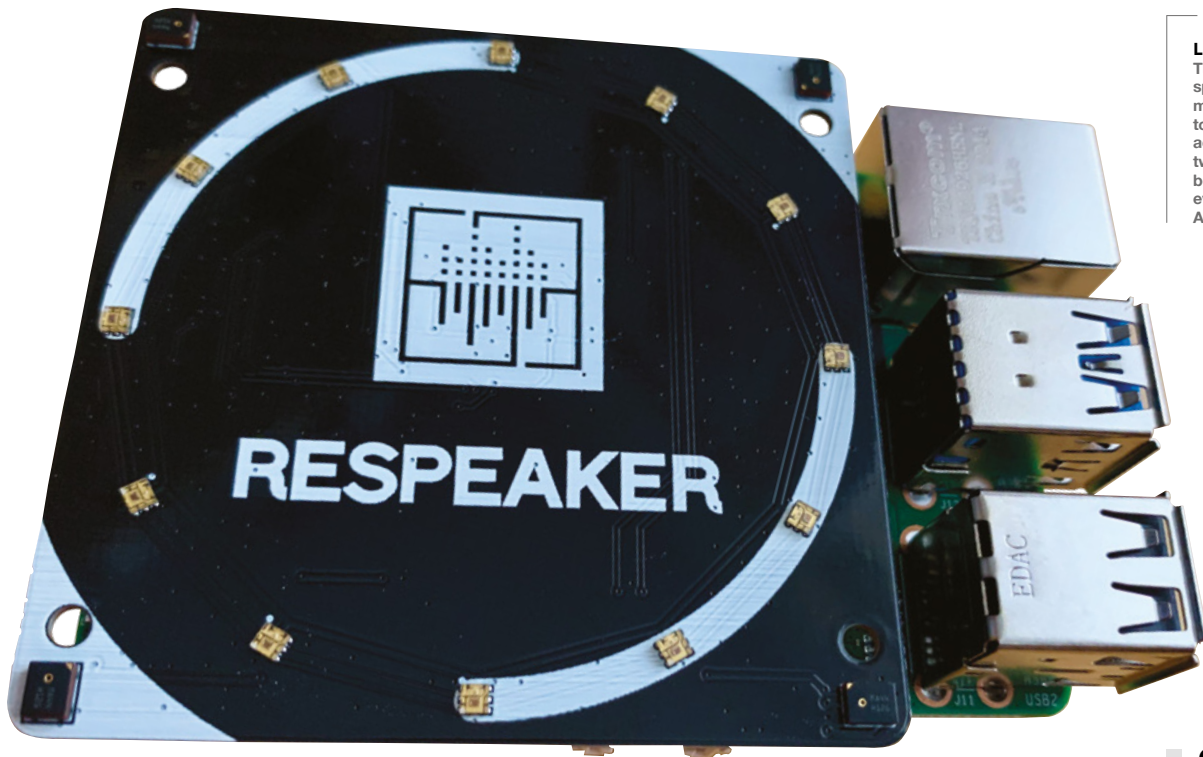There's also a two-microphone ReSpeaker for the Raspberry Pi Zero

of it) is called the model. Luckily, this whole process is handled for you at **snowboy.kitt.ai**, where you can create a model file in a matter of minutes and download it. Just say your choice of words three times, and you're done. Transfer the model to your Raspberry Pi 4 and place it in your home directory.

LET'S GO GOOGLE

After the trigger word is heard, we want Google's fleet of super-servers to help us transcribe what is being said. To use Google's speech-to-text API, you will need to create a Google application and give it permissions to use the API. When you create the application, you will be given the opportunity to download 'credentials' (a small text file) which will allow your setup to use the Google API. Please note that you will need a billable account for this, although you get one hour of free speech-to-text per month. Full instructions on how to get set up can be found using the following link: **hsmag.cc/DMKBuO**.

INSTALL THE SDK AND TRANSCRIBER

To use Google's API, we need to install the firm's speech-to-text SDK for Python so we can stream audio and get the results. On the command line, run the following:

```
pip3 install google-cloud-speech
```

(If you get an error, run `sudo apt install python3-pip` then try again).

Remember that credentials file? We need to tell the SDK where it is:

```
export GOOGLE_APPLICATION_CREDENTIALS="/home/pi/
[FILE_NAME].json"
```

(Don't forget to replace `[FILE_NAME]` with the actual name of the JSON file.)

Now download and run the test file at **hsmag.cc/mGPD6F**. Try saying something and see what happens!

PUTTING IT ALL TOGETHER

Now we can talk to our Raspberry Pi, it's time to link the hotword system to the Google transcription service to create our very own virtual assistant. We've provided sample code at **hsmag.cc/TZQIlu** so that you can see these two systems running together. Run it, then say your chosen hotword. Now ask 'what time is it?' to get a response. (Don't forget to connect a speaker to the audio output if you're not using HDMI.) Now it's over to you. Try adding code to respond to certain commands such as 'turn the light on', or 'what time is it?' □

QUICK TIP

With multiple Raspberry Pis, you can add a context to your instruction. 'Turn on the lights' can be specific to the room you are in.

YOU'LL NEED

→ **Raspberry Pi 4B** (earlier models will work too)

→ **Seeed ReSpeaker 4-Mic Array** (hsmag.cc/GtEwQz)

→ **Google account**

Make your own messenger bag

Rock the remote working look with a hand-sewn swag bag

Rosie Hattersley

🐦 @RosieHattersley

Rosie Hattersley writes tech, craft, and life hacks and tweets @RosieHattersley.

Bag makers seem to have two rules: black is always in fashion, and big is best. Yet many of us are perfectly at home with modest-sized laptops or large-screen tablets to see us through the working day. With that day likely to be a combination of various rooms in your house and the occasional trip to a café with Wi-Fi to break the home-working monotony, there's less reason than ever to tote a back-breaking tech behemoth or follow the corporate herd in your choice of bag. Carefully take the measurements of the tech you use, choose fabrics you like and, in just a few hours, you'll have a practical messenger bag that looks good too.

Heavy cotton or oilskin fabrics are your friends when it comes to fabric choice, but aside from that, it's carte blanche. You could upcycle something: our main fabric is from an unused roller blind – ideal because it's wipe-clean. Or, look on sites

such as Frumble for funky character designs. You'll need a jeans needle to cope with these thick fabrics, especially at assembly stage with several layers to stitch.

MEASURING UP

Decide what size bag you'd like. Measure the width of the laptop or tablet you're going to be carrying in it, then add 1.5 cm each side as the seam allowance. For example, this MacBook Pro is 32 cm wide, so the front fabric needed to be 35 cm wide (32+1.5+1.5). Use a similar calculation for the height. Cut a front piece based on your width × height measurements out of the main, contrast, and (optional) fusible interfacing fabrics.

The back of your messenger bag will be the same width as the front you just cut out, but also needs to include the front flap and the depth of the bag. A 10 cm depth (including the 1.5 cm seam allowance each side) is ideal. For a 25 cm tall bag, you'd need

Left
Strongly contrasting colours and patterns work well. A wipe-clean fabric that isn't shiny is ideal

Below
Invest in a heavy-duty sewing machine needle to get through thick layers of fabric

the back piece to be 25+10+25 cm = 60 cm tall. As before, you'll need to cut one from the main fabric, one from the contrast fabric, and one from the interfacing (if you're using any). See *Spot a pattern* box for advice before cutting out.

Give your bag rounded edges using the inside curve of a Patternmaster (if you have one), or use a compass or the edge of a plate.

> **Our main fabric is from an unused roller blind** – ideal because it's wipe-clean

The sides of your bag need to be the width plus two sides, plus 2 cm seam allowance at each end (25+35+35+2+2 cm in our case). It's wise to add a bit to accommodate any errors, such as having made your bag a bit wider having skimped on seam allowance. Cut out two pieces from the contrast fabric and the same from the interfacing if you're using some. Note that you could also add some padding here to cushion the base of your bag.

You'll also need a strap. If you have a bag you already use, measure the strap length at the size you use it (if it's adjustable) and cut out two strips 10 cm wide, plus the usual interfacing ones. Alternatively, you could reuse the strap from your existing bag if you prefer an adjustable canvas one.

POCKETS PLEASE

Make your messenger bag more useful by adding a pocket. If it's to be a phone pouch, lay your phone on the fabric and chalk (on the wrong side of the fabric) and draw a vertical line half a centimetre from the edges. Do the same if you want to add a key or card section. Cut two pieces 2 cm wider and longer than the finished size you want. With right sides of the fabric together, sew a 1 cm seam around three edges, leaving the top edge unsewn. Snip off the edges of the corners to reduce the bulkiness. Turn the pocket the right side out. Turn in the unsewn edges to make a 1 cm hem, and sew. →

YOU'LL NEED

- **1 metre each of main and contrast fabric** – heavy cotton or oilskin are ideal
- **Matching threads** (top-stitch thread optional)
- **Fusible interfacing or wadding** (optional)
- **Sewing machine**
- **Heavy gauge sewing machine needle** – a jeans needle is ideal
- **Sharp scissors**
- **Chalk or fabric marker pencil**
- **Dressmaking pins**
- **60 cm or longer steel rule**
- **Patternmaster or compass**
- **Hand-sewing needle**

You'll need to position your pocket one or two centimetres below the inside top edge of the back of your bag. To work out where this will be, measure up from the bottom of the contrast fabric you cut out for the back of your bag. Taking into account the 1.5 cm seam allowance at the bottom, work out where the top edge of the bag will be (the measurement you used initially) and pin the pocket centrally just below this point. Sew all but the top seam as close to the pocket seams as possible, then sew down the line you marked for the card pouch.

ASSEMBLY TIME

Iron fusible interfacing to the wrong side of each pattern piece (if you're using it). Use a tea-towel or ironing cloth to prevent it from sticking to your iron.

With right sides of the fabric together, pin and sew around three edges of the front, leaving a 1.5 cm seam allowance and ensuring the curves line up. Do the same for the back. Turn right side out and press the seams.

Repeat the process for the bag's side pieces, leaving one of the smaller sides unsewn so that you can turn it right side out. You should be able to do this by pinching and grabbing the inner fabric. See *Quick Tip* if the fabric proves resistant.

QUICK TIP

To get crisp edges and seams, push out seams using a blunt edge, then steam iron the seams (with a tea-towel to protect the fabric).
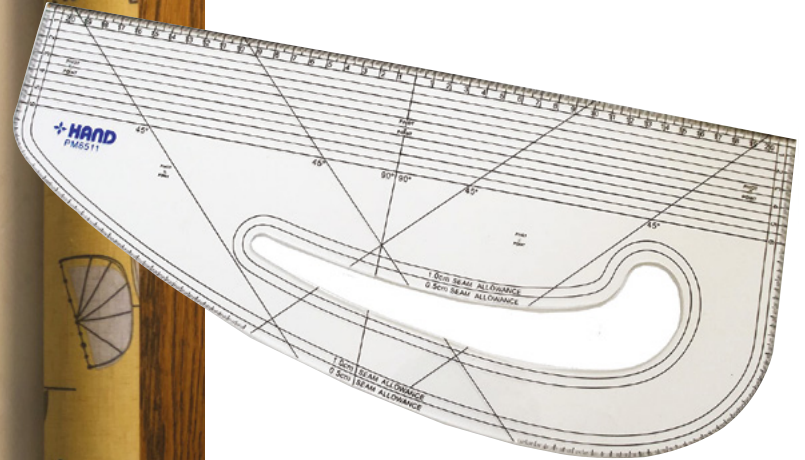
Mark a chalk line 1 cm from the top inside the unsewn front piece. Fold in the edge to this point with both front pieces, pin and top-stitch closed, smoothing out any trapped air. Repeat for the back.

With right sides together, pin the side to the front along three edges, starting with the sewn end and carefully aligning it with the top edge of the bag's front. Make sure you allow enough fabric to go around the curved corners. Sew the edge piece in place as close as possible to the edge. Next, sew the other side to the back of your bag. Press out the seams once more. Place your laptop or tablet in the bag to make sure it fits snugly. Fold over the front flap to check how it sits with your tech in place.

This is the time to make any adjustments, such as trimming off excess fabric from the strip that formed the sides. Leave at least 1 cm to form, fold in, and stitch the final side seam.

ZIP IT UP

To add a zip for security, cut out two extra strips of contrast fabric 8 cm tall, and the same width you cut out for your bag's front. Sew a 1 cm hem along each side. You want a zip with chunky teeth. It needs to be the width of your bag. Open the zip and pin the right side of each half along one of the long hemmed edges, starting at the top where the zip teeth begin (i.e. ignore the tape before it). Check the zip closes, and then sew the seams close to the zip teeth. Attach one edge with right sides together to the top edge of your contrast fabric bag front using a 1.5 cm seam allowance. Once the rest of your bag's assembled, open the zip and pin and sew the edges and back seam and sides. You may need to hand-sew some of this.

STRAP–HAPPY

Strap length will depend on your height and how you prefer to wear your messenger bag. For a shoulder-dangling bag, a strap 120 to 130 cm should work; a cross-body one will need to be 50 cm or so longer. You will probably need to make it in two pieces. Cut two very long 10 cm wide strips. If one of your fabrics is a stiff oilskin and the other heavy cotton, use the latter as it will be more comfortable to wear.

> **Strap length will depend on your height** and how you prefer to wear your messenger bag

Pin each piece right sides together and sew around three sides. Turn it the right way out and then flatten out the resulting tube so that the seam runs up the middle of one side. Sew up one of the final seams. Iron both pieces if you wish. Pin the ends that have squashed into triangles into place inside the bag, just beneath the top of the sides. Pin the other ends of the straps flat across their width and test the length.

Adjust the length as much as you need by pushing one strap inside the other. Pin in place at the required length and sew a couple of parallel lines of stitching across the width of the strap. Hand-sew the bag end of the straps around all three triangle sides. Your bag is now complete. ▢

SPOT A PATTERN

If you've chosen a large pattern, it's worth spending time making sure the most interesting bit is in the middle of your messenger bag design. Cut a piece of paper to the size of the bag's front and lay it on top of your fabric. Remember, it's the flap that will be visible on your finished bag.

Above ◆
Work throughout with the patterned (right) sides of fabric facing each other

Top Left ◥
Measure your phone and add a bit extra each side to allow for its depth when designing an internal pocket

Left ◆
Pin and sew the sides to the front piece first, making sure you account for the edges

QUICK TIP

Using contrasting thread to top-stitch your seams can look great, but only if you can confidently sew straight. If in doubt, match your thread to your fabric.
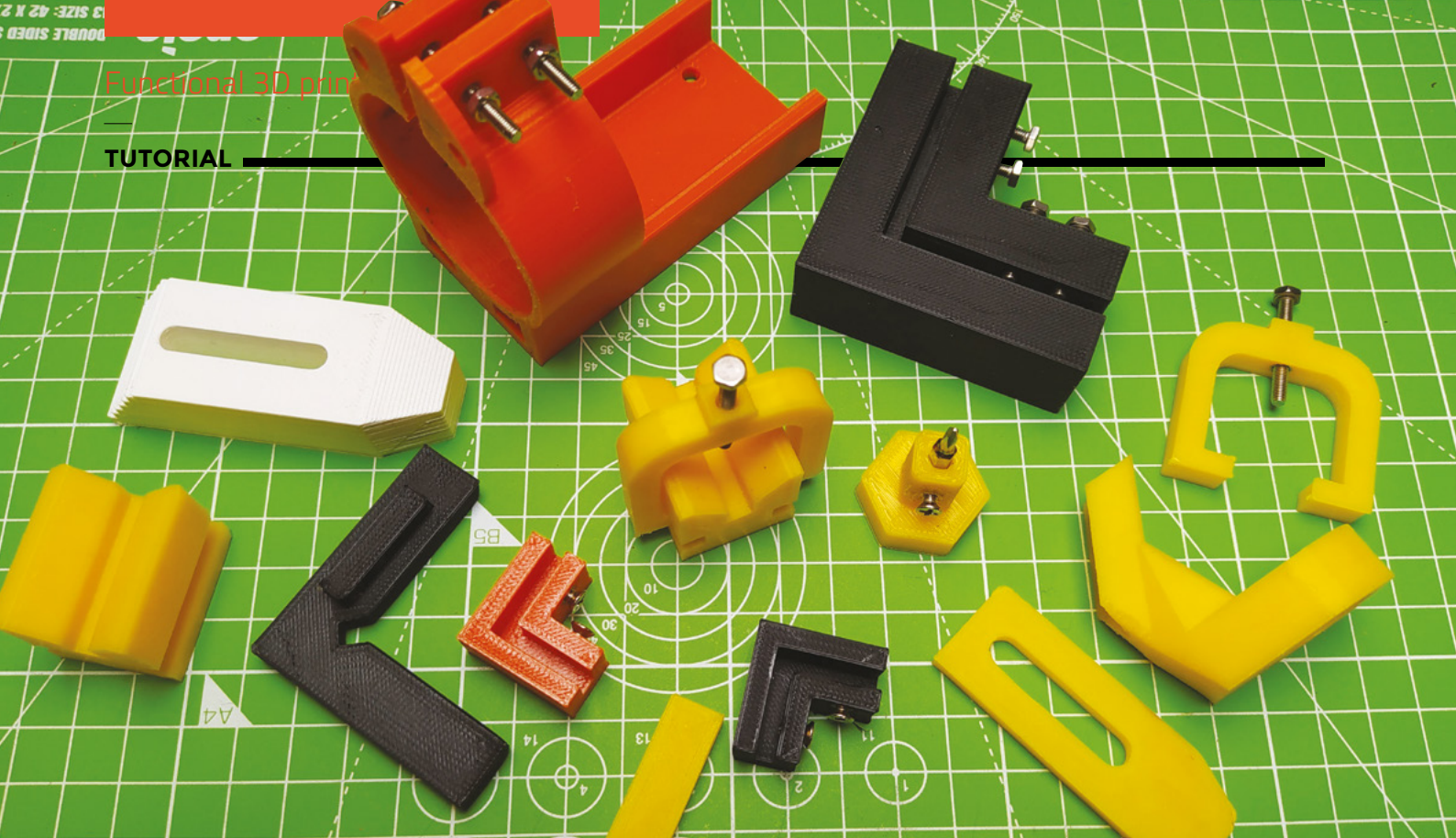
Functional 3D printing, jigs, and tools

While many people start off by 3D-printing geometric vases, action figures, or props from a favourite film, at some point you'll want to print something functional and useful

Jo Hinchliffe

🐦 @concreted0g

Jo Hinchliffe is a constant tinkerer and is passionate about all things DIY space. He loves designing and scratch-building both model and high-power rockets, and releases the designs and components as open-source. He also has a shed full of lathes and milling machines and CNC kit!

O**ne of the first functional 3D prints this author ever made was a set of small thumb-wheels that fit over the adjustment nuts on his 3D printer bed (Figure 1).** This bypassed the need to find a tiny spanner every time he want to adjust the bed on the printer, and made the process much quicker. He would probably, with hindsight, redesign these a little larger now. However, as one of the first prints he undertook, they still perform well to this day.

Making accessories for other machines has been a constant theme of our more functional 3D prints. One common job is printing custom clamps for use on our manual milling machine or CNC router. It seems that you can never have enough clamps and, for smaller machines, using a 3D print with a strong, high amount of infill is perfectly acceptable. In **Figure 2**, the small low-profile clamps work really well, are incredibly cheap to make, and can be printed quite quickly.

While we don't recommend crashing the CNC head into a clamp, they are easily replaced if damaged.

One of the beauties of CNC-type machines, laser cutters, CNC routers, and 3D printers is their accuracy. One of the first and most simple tools we make a lot on the 3D printer is a simple angle or square. In **Figure 3**, you can see our simple 90-degree square, which is incredibly useful in setting pieces at 90 degrees. We designed it with the point of the external corner cut away so it can be used in internal corners that perhaps we are gluing together without sticking the 3D print to the object. Using a combination of the square and a couple of clamps, it's pretty useful for enabling accurate gluing. Similarly, we printed a small gap on the internal angle so that it can still be used on the outside of an object, even if the object has a small radius. Whilst we have a stack of these at 90 degrees, it's also pretty easy to make any particular angle you might need to help you repeatedly set or glue items.
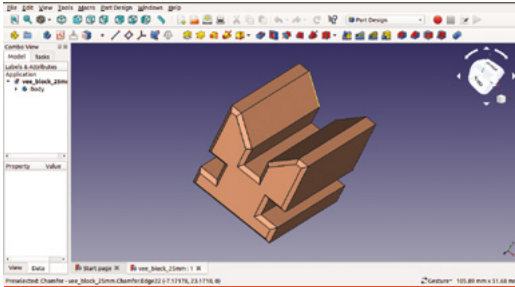
STARTER PROJECTS

A lot of the little tools and jigs and helpers we have made or shown in this article would make excellent starter projects for those learning a CAD package. Most of the objects could be made from combining simple shapes in CAD, and are not too daunting in complexity. Whilst we used the open-source FreeCAD software for the pieces we made in this article, these often simple designs could all be realised in any CAD package. Some more accessible CAD environments, such as the online Tinkercad platform, would be great for these starter projects. Some of the functional 3D prints in this article are ones we found on websites such as Thingiverse or GrabCAD. So, indeed, you might be able to find files for useful items without having to design them yourself.

IT'S HIP TO BE SQUARE!

In **Figure 2** you can see an adaption of the simple 90-degree angle idea. The black piece is again a 90° angle, but underneath it has a parallel raised section on one of the arms, designed to slot into the tee slots on our CNC router. This is a really useful tool that can be clamped into a position on the router bed, and then workpieces can be placed quickly into it and we know that the workpiece is square to the bed/axis of the machine. It's particularly useful if you need to repeatedly place the same size stock in the same position to create multiples of the same item, or indeed if you have a regular-sided object that you need to rotate and perform machine operation on multiple faces. You can also use it to zero the tool into the corner of the angle and then hold circular work in a known relative position to the zero point. **Figure 4** shows a small aluminium chassis (made for a PocketQube-class satellite) which had the features of each side machined, whilst rotated in a similar jig. Whilst there are more accurate ways of
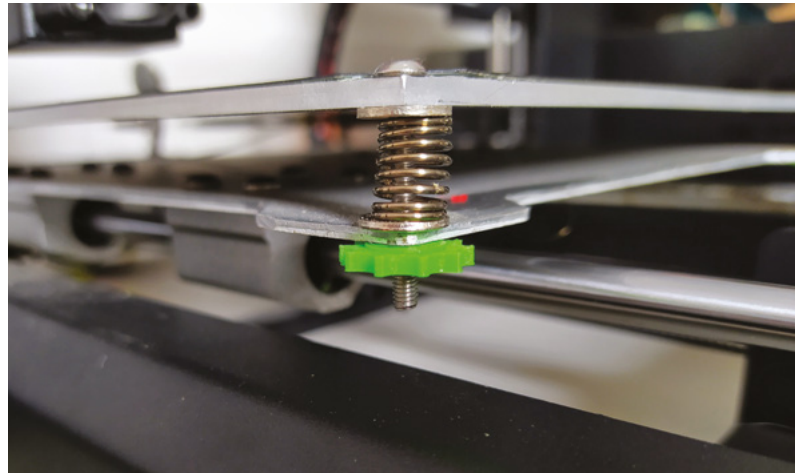
doing setups for machining, this approach can return good results quickly and within reasonable tolerances.

Finally, for 90-degree angled tools, we made these clamps that help hold specific stock at 90 degrees. They are designed to receive 3.125 mm plywood which we often use in laser-cutting projects. The design is a simple 90-degree slot, but is sized accurately so the wood is a reasonably firm sliding fit into the clamp. We've then added some threaded inserts into the printed holes, and they can now take M3 bolts to be hand-tightened onto the workpieces to make sure everything stays in place. For accurately assembling small butt joints, these work very well (**Figure 5**).

Vee blocks are more commonly made from steel, rather than 3D-printed, and are used in all manner of machining tasks and also for accurate marking out of work etc. One use is that they can clamp and hold →

> **Whilst there are more accurate ways of doing setups for** machining, this approach can return good results quickly

Figure 1 (top)
Some small thumb-wheels that make adjusting a captive nut position much less fiddly

Figure 2
CNC router clamps are a common print item – cheap to produce and strong enough for most jobs. A square work-setting angle is also a useful accessory

YOU'LL NEED
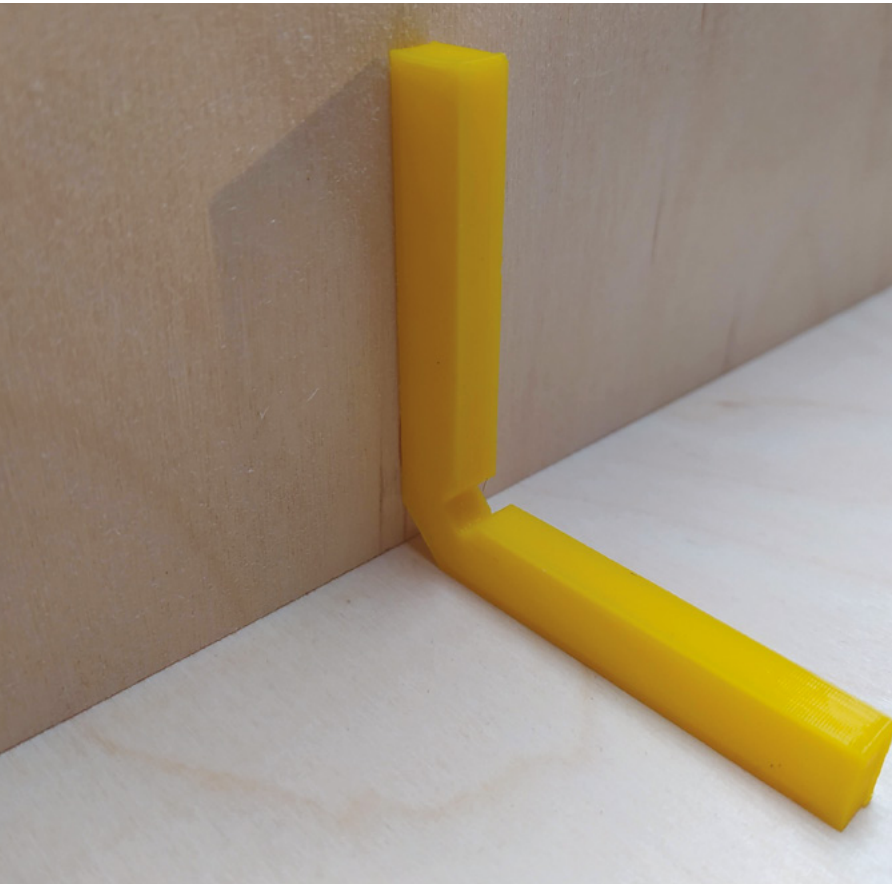
Access to a 3D printer and filament

THERMAL INSERTS

For a couple of our clamps and jigs in this article, we have used thermal inserts. These are small, brass nuts with a knurled gripped pattern on the outside, with a thread cut into the inside. They are used in industry and are heated and pressed into, usually, injection-moulded plastics to create strong threaded joints. They can be used well in 3D-printed objects, and you can find out the diameter of the hole you need to press them into in the thermal inserts data sheet. The M3 ones we have require a hole of around 4.2 mm, and we tend to put them into holes printed with at least a 1.2 mm wall thickness. You can heat the insert for a few seconds with a soldering iron and then use another metal tool to push them into the 3D print. We went one step further and modified a Dremel workstation/drill-press to have a soldering iron attachment and modified the soldering iron tip to help insert the inserts. We mention this as we used a good example of functional 3D printing in the process of the conversion. We made the first iterations of the idea using 3D-printed plates until we were sure we had the correct positions of all the holes, and then we simply used the 3D print as a drill template by attaching it to the piece of steel stock we wanted to use for the final assembly (**Figure 6**). This is a great process, costs little, and increases the chances of creating a successful part when you commit to the final material. It's pretty accurate when you don't need extremely small tolerances, and also means you spend less time marking out and centre-punching workpieces.

Figure 3 ◈
Simple angle tools are easy to make on a 3D printer with good-enough accuracy to help with many tasks
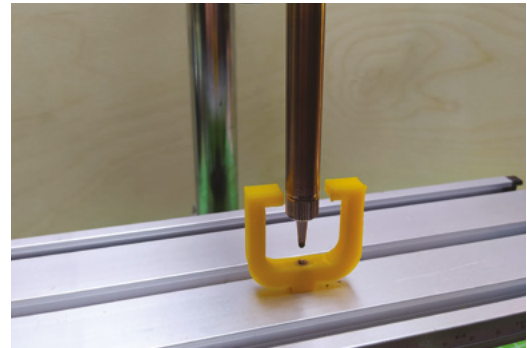
Figure 4 ◳
Each face of this cube was machined on our CNC as a separate job, using a jig similar to the one seen in Figure 2

round bar stock very well and same size collections of vee blocks are often used to hold longer workpieces. We needed three matching vee blocks that we didn't have in our collection of metal ones and, as the job didn't require huge accuracy (as in we didn't need to machine the part to 0.02 mm, but rather a 0.1 mm tolerance would suffice), 3D-printed vee blocks are a cheap and quick replacement (**Figure 7**).

We quickly CAD'd the block geometry in FreeCAD as a simple extrusion, and we made a small chamfer on one end. The chamfer end of the block is the face that sits on the print bed. Adding the small chamfer means that any sagging of the first layers of the print, often referred to as 'elephant's foot', is absorbed by the chamfer, then the base and vee sides of the block don't have any lip on them. It's a quick and simple way to increase their accuracy. We went the whole hog with the vee block design, and also designed a clamp that fits into the side rail slots of the vee block. The clamp section again has a thermal insert pressed into it so that it can have an M3 bolt inserted, and this can apply the clamping force down onto the workpiece. The clamping force, in this instance, is therefore pushing up into the clamp, so we made sure to place the insert inside the clamp to maximise the strength.
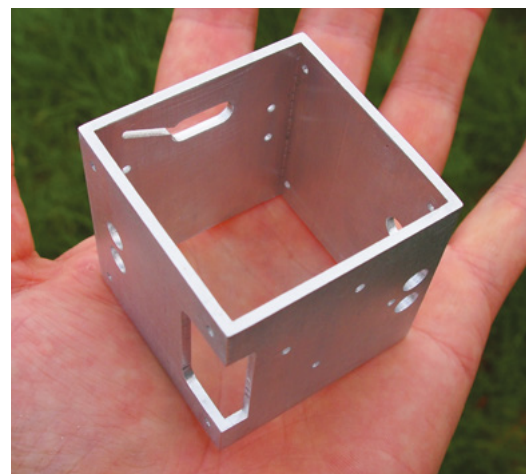
QUICK TIP

We say it a lot, but always wear your PPE and eye protection when grinding with a rotary tool.

A simple tool we love, which is available in multiple different forms on sites such as Thingiverse and GrabCAD, the Dremel drill-sharpening adapter is a really useful little device that enables drills to be quickly reconditioned. Again, this is in no way as accurate as a proper drill-sharpening grinding system but, for the average use case where absolute accuracy is not that critical, it's a perfect way to clean up a dull drill bit, or even to totally reform a broken one. Searching online, you can find many variants of this little tool, and you should be able to find one

> **Holding the broken or dull drill bit in the vee groove** presents the drill at the correct angle

that matches your Dremel or other brand rotary tool. The printed tool threads onto the threaded adapter on the Dremel, and you insert a grinding wheel/stone accessory. Holding the broken or dull drill bit in the vee groove presents the drill at the correct angle; this then allows you to rotate the drill end against the grinding wheel and sharpen the bit. In **Figure 8**, you can see the arrangement – this 5 mm drill bit had been previously snapped in half, but was quickly sharpened back to a usable standard. →

Figure 8 ◆
A Dremel drill bit sharpener attachment by justinds89, found on Thingiverse

Above ◆
A hands-free Dremel clamp by WillemvD found on Thingiverse
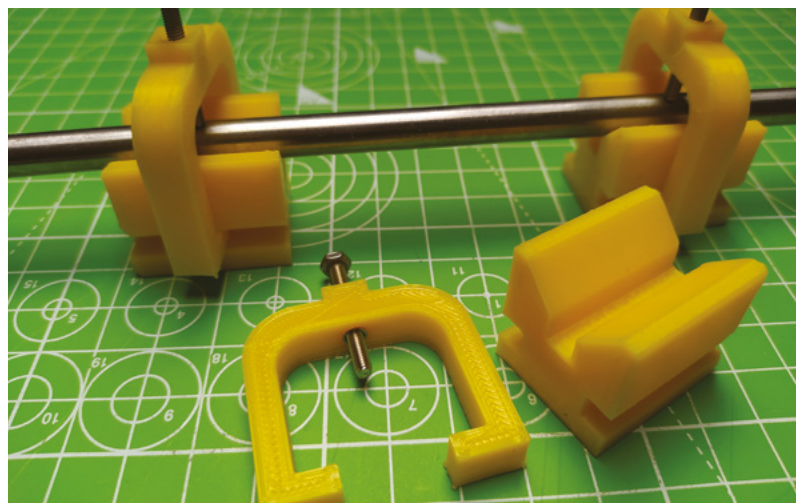
Sticking with Dremel and rotary tool accessories, there are lots of 3D-printable projects to be found online that increase the use cases of these tools. A simple project that we found online was an accessory that clamped a Dremel 3000 to a work surface. This larger print took around two hours to print, but is an excellent accessory that allows hands-free usage of the Dremel – particularly useful when sanding or grinding small objects. Our version was designed to fit our older Dremel 3000, but looking around online, people have modelled similar clamps for many models of Dremel and other brands of rotary tool.

" **There are lots of 3D-printable projects to be** found online that increase the use cases of these tools "

Finally, continuing the theme of expanding the use cases of tools, one final functional 3D print that we have done is a small holder for screwdriver bits. We have numerous sets of the 4 mm hexagonal shanked screwdriver bits, and occasionally we have ended up using just the bits with a small pair of pliers to turn it from the side, enabling access to a difficult-to-reach fastener. This is probably not recommended, and it's easy to drop a bit into whatever you are working on, so we quickly designed and printed a low-profile bit holder. A simple hexagonal block with a shaft that can receive the 4 mm bits is finished with, again, a thermal insert on the side in which we can use a grub

screw to clamp the bit in, making sure we don't lose it (**Figure 9**). It's incredibly handy occasionally, and a great tool to print multiples of and give away as a gift to other makers! At some point we will experiment with embedding a magnet into the print as an alternate method of bit holding.

We have put all the files for the tools, jigs, and clamps that we have designed on Thingiverse (**hsmag.cc/bYBGRn**), and those designed by others can be found available for use online. That said, these simple prints are great opportunities to learn a few basic CAD skills! ▫

Figure 9 ◆
A simple stubby tool to hold common 4 mm screwdriver bits
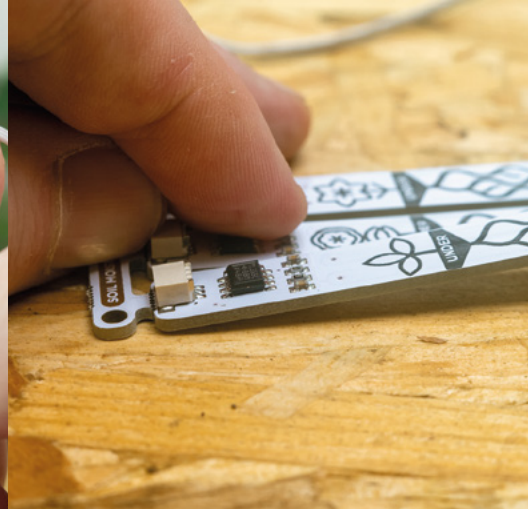
Grow

pimoroni.com/grow
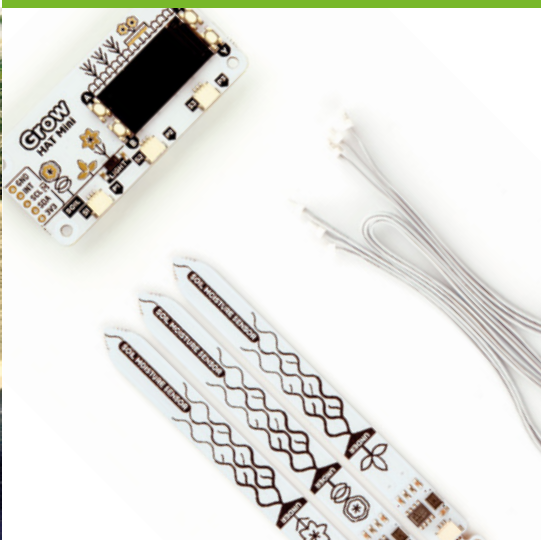
Etching and laser cutting for art and electronics

Use a laser cutter to make etchings in copper, brass, aluminium, and steel

Dr. Andrew Lewis

Dr. Andrew Lewis is a specialist fabricator and maker, and is the owner of the Andrew Lewis Workshop.

C O_2 **laser cutters, like the K40, are great for etching and cutting detailed designs into plastic and wood, but etching metal presents a bit of a problem.** The frequency of a CO_2 laser doesn't have much effect on metal, so making a real etch needs a bit of creative thinking. In this article you'll see how to use a K40 laser to simplify the process of chemical etching, and learn about some of the common chemicals used to etch different types of metal.

The process of etching metal isn't complicated. If you dunk a piece of metal into the right type of acid, it will start to dissolve. The tricky part of the process is protecting the parts of metal that you want to keep. Typically, you apply a protective coating (called a mask or etch resist) to the areas you want to keep,

and the acid reacts more slowly with those areas. The really difficult part is applying the mask in a precise pattern. For example, there are UV-reactive resists that allow you to apply the mask and develop it like a photograph using UV light and a negative. All of these methods work, but they're all very messy and fiddly to work with. If you have access to a laser cutter, the whole process gets much simpler, because although the CO_2 laser can't etch the metal directly, it can remove an etch resist from the surface of a metal plate.

The techniques we're about to show you use powerful lasers and corrosive chemicals, so make sure you understand the safety implications of this before attempting your own etch. It shouldn't be too onerous: use your usual laser cutter safety processes and handle chemicals responibly.
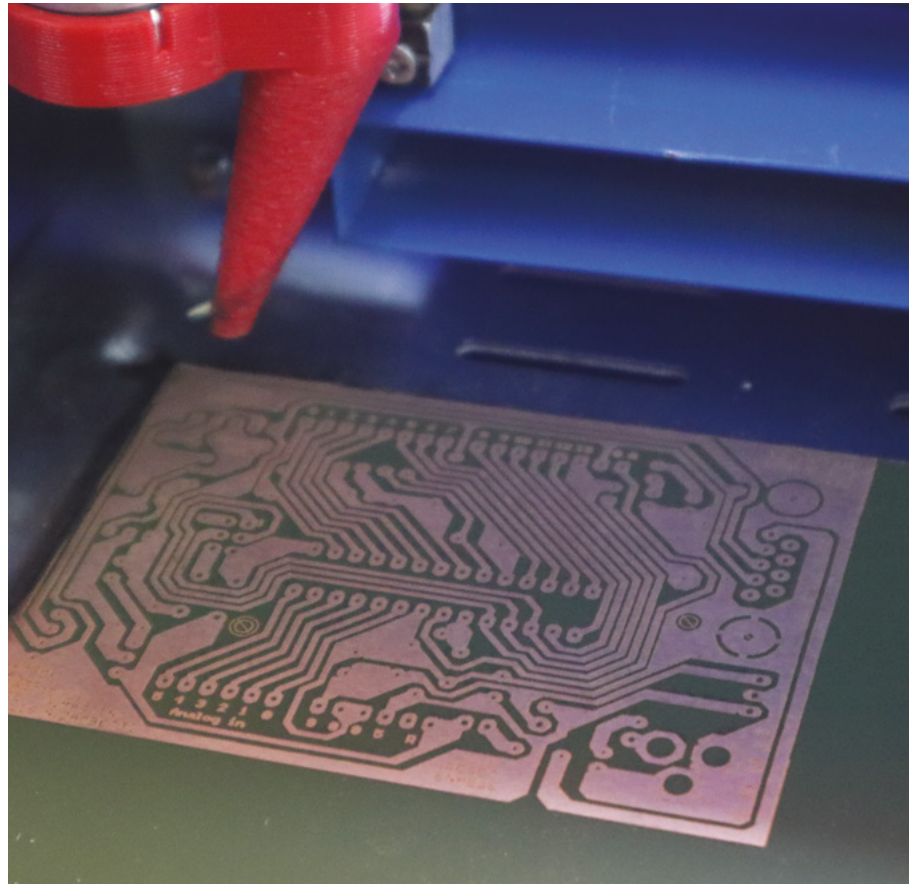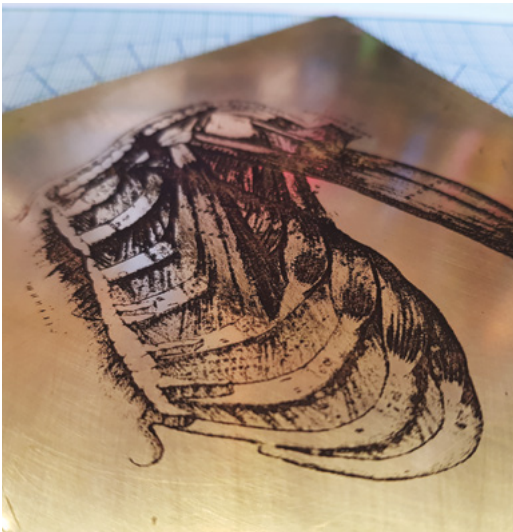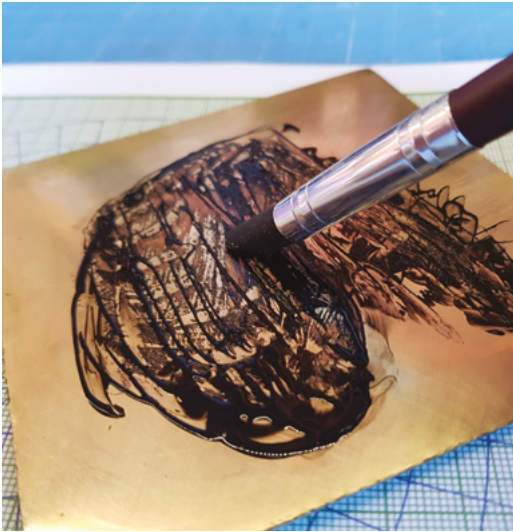
GET YOUR IMAGE READY

Preparing an image for etching a PCB can be a bit confusing, particularly if you're familiar with the transfer method, which flips the image to account for the reverse transfer from the paper to metal. When working with a laser etch, you don't need to flip the image because you're etching the mask directly. You might need to invert the colours in the mask, depending on what software you used to generate it. The laser will etch away the black parts of the image. So, for a PCB, that means your tracks and any other parts that you want to be copper should be white on the mask. For printing plates, the printed lines and hatches should be white in the mask.

EVEN METALS WEAR A PROTECTIVE MASK

It doesn't matter whether you're using a sheet of brass plate, bronze, steel, or a copper-clad printed circuit board, the process always begins with cleaning and degreasing. Remove any dirt and grime from the plate with soap and water, then dry it, and key the surface of the metal lightly with fine wire wool. Wipe with water, and then degrease with alcohol or acetone and let it dry.

> **Using a jig to hold the sheet in the correct place** is helpful if you're working on multiple pieces

Acrylic paint makes a great etch resist, and it is easy to remove with acetone or other solvents. Spray your sparkling clean sheet of metal with matt acrylic paint and let it dry. Load the dry sheet into the laser cutter as squarely as you can. Using a jig to hold the sheet in the correct place is helpful if you're working on multiple pieces, or are using a double-sided PCB. →
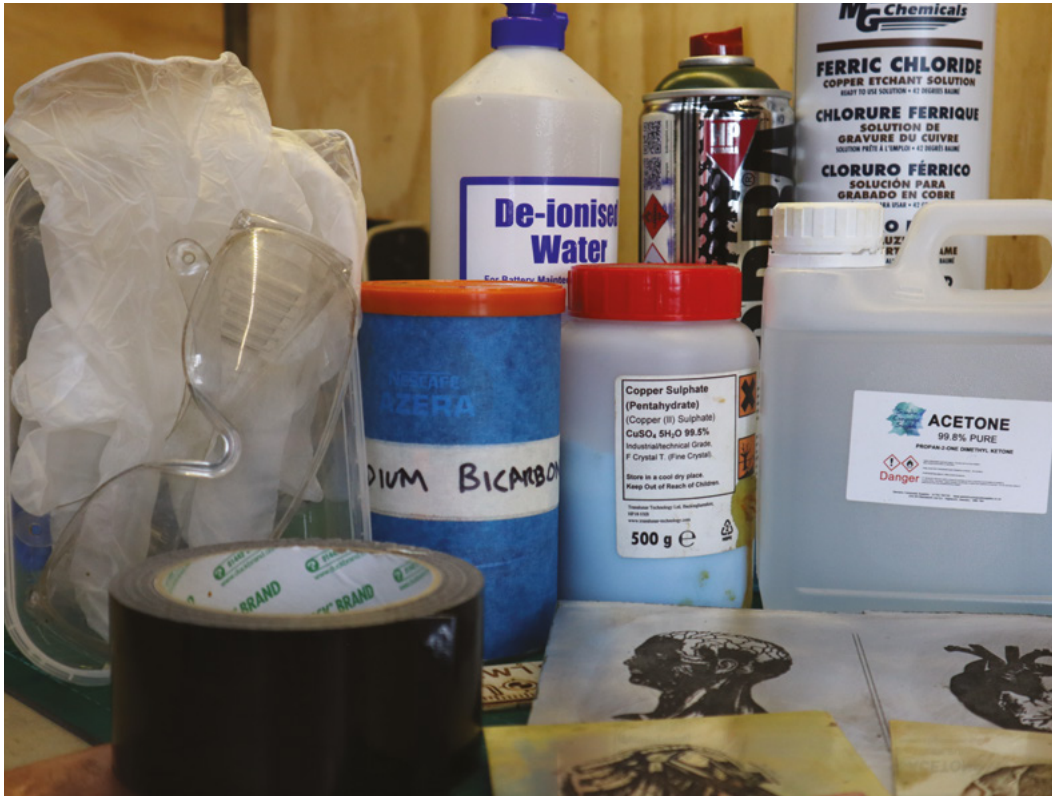
Above ◈
For an upgraded K40 with a good lens and mirrors, about 8 mA (roughly 25% power on properly set digital machines) with a 250 mm/s travel speed should remove the mask well

Left ◈
Applying some contrasting acrylic paint to an etched plate only takes a few seconds, but really makes the detail stand out

QUICK TIP

You can speed up the paint drying process with a hot air gun.

Left
This project involves solvents, various types of acid, harmful chemicals, and invisible lasers that can blind you in a fraction of a second. All of these things require appropriate safety equipment, training, common sense, and situational awareness. Be safe, read the COSHH (Control of Substances Hazardous to Health) safety sheets, wear appropriate safety equipment, work in a well-ventilated area free from any other distractions. Neutralise and dispose of waste chemicals responsibly, and make it clear to other people when an area is not safe for them to enter

Below
Acetone is a popular solvent, and it will dissolve a whole range of different chemicals, including those that form the plastics used in disposable gloves, cutting mats, varnish, and some types of flooring

YOU'LL NEED

- **400 ml can of black acrylic spray paint**
- **1-litre ferric chloride** (optional)
- **Citric acid** (optional)
- **Salt** (optional)
- **Copper sulphate** (optional)
- **Acetone**
- **Water**
- **Gaffer tape**
- **Wire wool**
- **Disposable gloves**
- **Goggles**
- **Paintbrush**
- **Copper-clad board** (optional)
- **Copper, aluminium, steel, or zinc sheet** (optional)

Fire up your laser control software, and load in the template that you want to etch. The settings for your laser will vary depending on the tube, lens, mirrors, and type of paint you've used. Dial in your laser settings by running a test with the laser power low at about 4 mA and the speed at 250 mm/s, and gradually increase the power until you are getting a consistent removal of the mask from the metal.

> **The settings for your laser will vary depending on the** tube, lens, mirrors, and type of paint you've used

Etch the piece with the laser, and then use gaffer tape to mask off the back of the metal plate, leaving a loop of tape on each side to work as a handle. Put the plate in the plastic tray, then pour over your acid solution.

WOULD YOU LIKE TO SEE MY ETCHINGS?

Etching time for a plate varies depending on the solution used, the temperature and age of the solution, the type of metal, and several other factors. For a copper PCB with fresh ferric chloride at room temperature, you should see the copper disappearing in about 15 minutes. For aluminium with a dilute ferric

ETCHING OPTIONS

Different metals use different etching solutions. Aluminium is much more reactive than copper, so it typically needs a much weaker solution to etch. Not all etching solutions work with every metal, but ferric chloride is a general all-round etching solution for non-ferrous metals, while copper sulphate solutions work well on mild steel. Here are some of the more common etching solutions:

COPPER SULPHATE
Very simple to make, a mixture of copper sulphate powder and water. You can etch steel, zinc, and aluminium with this mix, although disposal of spent solution might be a bit difficult.

EDINBURGH ETCH
Ferric chloride mixed with citric acid gives a cleaner etch with copper and mild steel plates.

FERRIC CHLORIDE
This is the classic etching chemical. When mixed with water in equal parts, it reacts to form hydrochloric acid. It's fairly aggressive, but off-the-shelf 40% solution (about 40 Baumé) can be used neat on copper, brass, and zinc. For aluminium, it should be diluted at about four parts water to one part ferric chloride. Using the undiluted solution on aluminium will generate a lot of heat, dangerous acidic vapour, and will ruin the quality of the etch.

MORDANT
A mixture of salt and copper sulphate – good for etching most metals except copper. Less toxic than most other etchants, but still needs to be handled carefully.

NITRIC ACID
As you might expect, this is a strong and dangerous acid. It's also one of the more traditional acids used to etch printing plates. Very dangerous to use, and not recommended for anyone but the most experienced user. Gives off extremely harmful vapours and can dissolve meat. You are made of meat.

You can find much more information about etching online, and the Ironbridge Fine Arts and Framing website at **hsmag.cc/DoU9E0** is a great place to start.

chloride solution, a few minutes might be sufficient to etch the plate. Iron and steel can take several hours to etch, as can aluminium when using a weak mordant solution. Slower etching means less heat, and usually more detail, although leaving an etching plate in solution too long will result in undercutting at the edges and a loss of fine detail. With so many variables in play, some experimentation will be necessary, and it's best to keep a close eye on the process until you're happy that you can get consistent results.

When the plate is etched to your satisfaction, you'll need to remove it from the etching solution and clean it. If you're using ferric chloride, washing the plate with water and bicarbonate of soda should neutralise the acid. You can keep the etching solution and reuse it multiple times. Other etching solutions will need to be treated differently, and it's best to read up on the methods of safe disposal for any chemicals if you're unsure of how to get rid of them.

Dry the plate and then remove the acrylic paint by wiping it with a paper towel and acetone. You should now have a nice detailed etching that can be polished, a printing plate, or a printed circuit board that's ready to be drilled. ▫

Build your own musical tentacle

Squeeze and stroke your notes out of this soft circuit creation

Helen Leigh

🐦 @helenleigh

Helen turns all sorts of unusual items into musical instruments (amoung other things).

Soft circuitry is really fun. Instead of all the sharp corners and pokey angles that come with your usual electronics projects, this sound project was designed to be held, squished, and loved. I actually started making these comforting creatures as a response to a time in my life where I was worried about a lot of things. I wanted to make something that helped make me feel less anxious and more relaxed. So I came up with the idea of making a big plushy tentacle that cuddled me and made one of the world's most relaxing sounds when I cuddled it back: the bassy purr of a happy cat.

PATTERN

Start off by drawing your pattern. You will need to prepare two pattern pieces, one for the outside part of the tentacle and one for the inside. Both these pattern pieces should be around one metre long. The top of the outer tentacle should measure 25 cm wide, and the inner tentacle should start with a measure of 20 cm wide. Both should gradually taper down the one-metre length of the pattern to a rounded point.

If you don't want a tentacle the same size as mine, you can choose to make it any size that you like, as long as you stick to the rule that your inner tentacle pattern piece should be equally as long but slightly narrower than your outer tentacle pattern piece.

Once you have two tentacle pattern pieces that you are happy with, cut them out ready for pinning.

MATERIAL

Pin each of your pattern pieces to your chosen material. I chose a plain, medium weight white cotton for the outer tentacle and a textured, heavier weight white cotton for the inner tentacle. I like the effect of contrasting textured cotton on the inner tentacle, but you can choose any colour or texture combination that catches your eye: colourful cotton, strokable velvet, hipster plaid, cute polka dot, or even light denim. Just stay away from any kind of fabric that is stretchy and you'll be fine.

Right ◈
You can make your tentacle any length you like, but mine is about one metre long

Use sewing pins to secure the two pattern pieces to your fabric, then use a sharp pair of scissors (fabric scissors, if you have them) to cut out the fabric pieces. You can now remove the pins.

SEW RUCHING

Now it's time to sew! The first thing we're going to sew is the ruching on the inner tentacle. This ruching technique is what gives the tentacle its organic-looking curl. We're also going to use conductive thread to sew the ruching, turning our tentacle into a sensor-cle! I wanted to use conductive thread on both my top and bottom stitches, so I used Madeira HC40. If you have a different type of conductive thread, you'll probably only be able to use it as the bottom thread. Take a look at *Conductive threads* (page 95) for more information.

Wind your conductive thread onto a spare bobbin then insert into your machine. Thread your top thread and bring the bottom thread up ready to sew. Test your thread on some scrap material to make sure it plays nicely with your machine.

Set your machine to the zigzag setting, with a medium stitch length and width. Pin some sewing elastic to the centre of the widest part of your face-down inner tentacle piece, then secure the whole thing in place underneath your needle using the presser foot. Start sewing down the centre of the tentacle, securing the elastic in place as you go.

To ruche the fabric and give it a tentacle curl, you're going to need to start pulling on the elastic as it goes through the machine, starting with zero tension at the top and pulling more and more as you progress to the tip. This technique takes a little practice to perfect, so feel free to try it out on smaller bits of fabric

with ordinary thread first. I use one hand to steady/steer the back of the material and one hand to pull the elastic. By the time you reach the tip, the elastic should be fully extended to give the maximum curl.

SEW TENTACLE TOGETHER

After you have completed the conductive ruching, snip off the excess elastic and thread, then set up your sewing machine with ordinary sewing thread at both the top and bottom. Switch your thread to a small to medium stitch length and select a straight stitch.

Next, we need to sew the ruched inner and unruched outer tentacle pieces together. These pieces will eventually be turned inside out for stuffing, so place the outer faces of the fabric together and sew down the long edges, giving yourself 1–2 cm as a seam allowance. Do not sew →

YOU'LL NEED

- **Sewing machine**
- **Hand-sewing kit, including needles and pins**
- **Soldering iron and solder**
- **Scissors**
- **Bare Conductive Touch Board**
- **30 cm insulated wire, ideally braided**
- **2 m cotton fabric, ideally 1 m each of two contrasting colours or textures**
- **Cotton thread and conductive thread**
- **Tracing paper and pencil for drawing the pattern**
- **Metal press studs**
- **Sewing elastic**
- **Wadding**

the tops (wide edges) of the tentacle pieces together or you won't be able to get your electronics inside! I found it easier to have the ruched inner tentacle piece facing me, as you need to make sure it is stretched into the correct place while you sew.

Start sewing at one corner of the widest part and work your way down one of the long edges, pulling the ruched edge to meet the unruched edge as you go. Don't worry if it's not perfectly straight: this is a fairly forgiving sewing project. A few lumps and bumps make it more organic-looking anyhow!

When you reach the narrow end of your tentacle, slow down and curve the path of your thread around the corner. To change the angle of your sewing path, you can stop sewing while the needle is in the material, lift up the presser foot, pivot your material around the needle, then put the presser foot back down and continue sewing. It does not overly matter

> **"**
> Don't worry if it's
> not perfectly straight:
> **this is a fairly forgiving**
> **sewing project**
> **"**

if there is excess material at the end of either side of the tentacle. As long as the curve is good and the edges meet on both sides, you can always trim off the excess, and no one will be able to tell the difference.
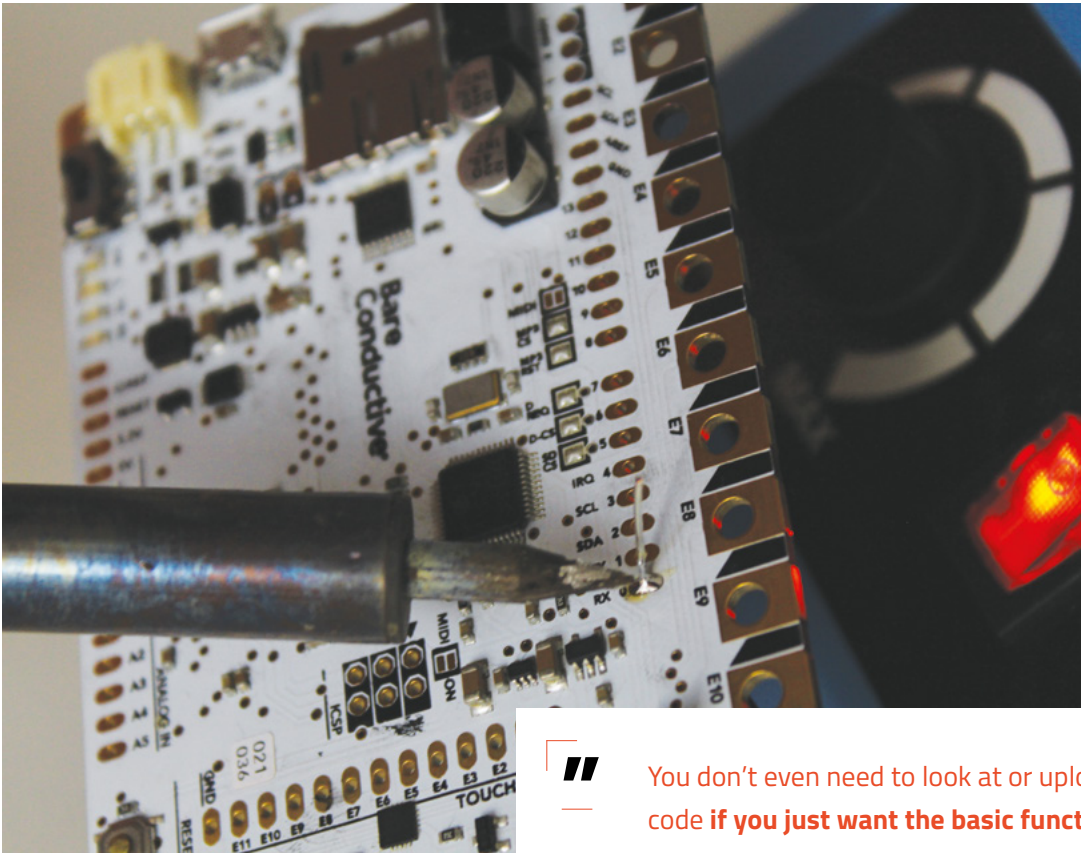
Once you have successfully navigated your sewing U-turn, you should head on back up to the top of your tentacle. Continue to pull the ruched edge to meet the unruched edge as you go, until you are done. Snip off any excess thread and material and move on to the next step.

STUFFING YOUR TENTACLE

This is a fun step. Push your (clean!) hand all the way inside your tentacle and reach for the very tip. Grab hold and turn it all inside out. Take a small clump of wadding and use your fingers or a chopstick to push it all the way to the tip of the tentacle. Keep adding small clumps of wadding, shaping as you go. After the first 10 cm of tentacle is stuffed and shaped, you can start adding in bigger clumps of wadding until you have fully stuffed your plushy sensor-cle.

PREPARING YOUR BOARD

So we have a tentacle, now here's how to add electronics to make it purr – or maybe even growl if that's more your cup of tea! For this project, I chose to use a Bare Conductive Touch Board.

> You don't even need to look at or upload any
> code **if you just want the basic functionality**

They're not the cheapest boards in the world, but if you have a project that combines touch and sound, you're going to be hard-pressed to find something that works with such reliability and simplicity. I often use these attractive Arduino-compatible boards with students who have limited knowledge of microcontrollers: they are such a satisfying easy win. You don't even need to look at or upload any code if you just want the basic functionality – touch something to play something.

WIRING THE BOARD
By this point, you should have a Touch Board with your chosen sound on it and a tentacle. Next up, we need to put them both together. When using hard electronics boards in a soft circuitry project, I often use metal press studs as connectors. They are easy to hand-sew, easy to solder, and easy to snap on and off. This means that you can detach boards and sensors from the soft parts of your project if you need to wash the fabric or reuse a board for another project.

Take one pair of uncoated metal press studs and use conductive thread to securely sew one of them to the inside of the tentacle, at the top of the zigzagged conductive thread seam you sewed earlier. It is very important that you make a good connection between the press stud and the zigzagged seam.

Solder one end of a length of wire to your Bare Conductive Touch Board on the E0 pin. There are two pins marked E0, the larger golden one at the edge and a smaller-headed pin. Either of these will trigger **TRACK000.mp3**, but the smaller pin is more suitable for connecting a single wire. Bend the other end of the wire into a small circle and place it into the recess of the second metal press stud, then solder it together. This is far easier with a set of helping hands! →
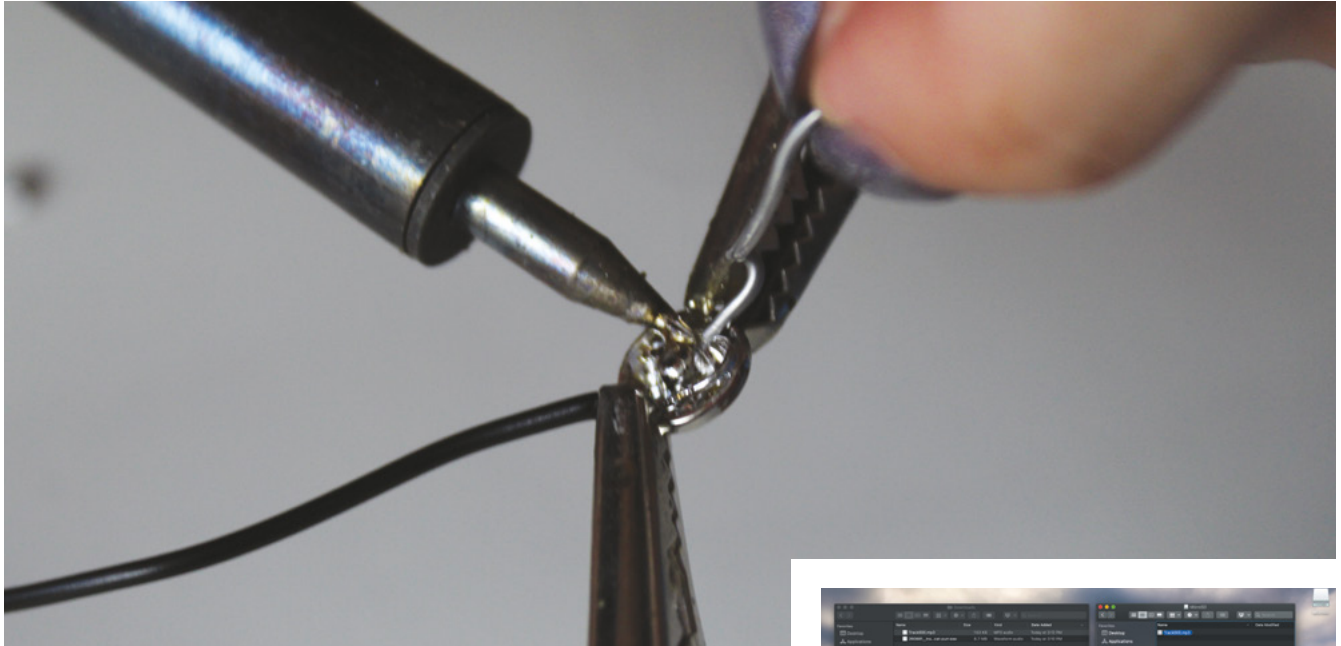
FINAL ASSEMBLY

Use the snaps to connect the board to the tentacle, then add in a battery to power your board. You can use a LiPo battery or a micro USB cable with a rechargeable power bank. Switch the board on, plug in your headphones, cuddle your tentacle, give it a stroke, and enjoy the purr – or whatever sound you chose to use.

GOING FURTHER

There are loads of options for taking his make further. To start off with, there are eleven additional pins that you can use to trigger different audio file options. You could use more conductive thread to hand-embroider additional trigger points to the tentacle, connect oversized metal press studs to represent 'suckers', or even make more limbs and connect them by making a central body. Whatever you decide to do, follow the instructions to connect each new part of your sonic circuit to the next available pin on your board.

Above ◈
Solder wires straight onto the snaps

Below ◈
You can plug earphones directly into the Bare Conductive board
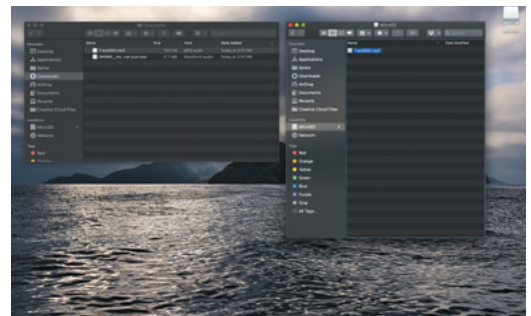
GETTING YOUR AUDIO

The board comes preloaded with code and an audio tutorial to help you figure out how it works, so all you need to do is choose and save the sound you'd like your tentacle to play. You can record your own audio, or you can select from an online audio library such as **Freesound.org** that holds audio files released under Creative Commons licences. Make sure your audio file is an MP3 file. If it's a WAV or any other type of file, you'll need to convert it to MP3 using audio software or an online audio file converter. Once you have chosen your MP3, save a copy of it onto your computer as **TRACK000.mp3**.

The Touch Board comes with a microSD card. Remove the microSD card from the board and insert it into an SD card reader. Connect the card reader to your computer, and you should see the microSD card show up as an external drive. Look at the contents of the microSD card and you'll see why I told you to name your file **TRACK000.mp3** – it's the naming convention used for the twelve tracks you can trigger by touching each of the twelve electrodes. When you touch electrode E0, **TRACK000.mp3** will play. When you touch electrode E1, **TRACK001.mp3** will play, and so on.

Save your chosen sound as **TRACK000.mp3** onto the microSD card, replacing the tutorial track the board shipped with. Eject the microSD card, remove from the reader, and insert back into the board.

CONDUCTIVE THREADS

There are many different types of conductive threads on the market these days, all with slightly different properties. I've tried most of the widely available threads out there, so here's my rundown of what to expect, and which are best for different applications.

Most of the electronics hobbyist online stores sell perfectly good conductive thread: Adafruit, Pimoroni, Kitronik, and SparkFun, as well as more specialist e-textiles online stores such as **lessemf.com** in the USA, or **lightstitches.co.uk** in the EU. You'll typically find two types of thread: a softer, hairier yarn-like thread or a waxier, more rope-like thread.

The waxier types can often be used in the bottom thread (i.e. on the bobbin) of a sewing machine. I have not successfully used these types of thread in a top thread. This type of thread is sturdy and does not fray, unlike the thinner, hairier type of thread. However, the waxy conductive threads tend to be reluctant to stay in a knot once tied off, leading to short circuits and sad times. Stop your thread unravelling by securing knots with a dab of clear nail varnish or some glue.

The thinner, hairier type of thread is not ideal for use in sewing machines, as I find it tangles and breaks too much. It is great for hand-sewing in projects where the thread will be touching the skin, for example, turning your favourite gloves into touchscreen gloves. This thread knots easily and usually stays knotted. However, you need to be really careful with the hairs on this type of thread, particularly if you're buying a cheaper brand. These tiny hairs are short circuit city! I've used a quick spritz of anti-frizz hair-spray to tame this thread before, which has worked really well. My favourite conductive thread for sewing machine work or ordinary hand-sewing is Madeira HC40 machine embroidery thread – £32.99 for 250 metres from **lightstitches.co.uk**, or direct from Madeira in the USA.

Madeira is a well-known brand in machine embroidery, and the HC range is their foray into conductive threads. They know what they are doing. This thread has never failed me in a machine by breaking, tangling, or bunching up, which is more than I can say for many ordinary cotton threads! Unlike many other conductive threads, the Madeira HC40 can be used in both the top thread and in the bobbin at the bottom. It's a pleasant but unremarkable silvery colour. It is not suitable for soldering. This thread is my go-to for pretty much all electronic embroidery projects. My favourite conductive thread for hand-sewing (and soldering!) is Karl Grimm's copper and silver embroidery threads. It's 57 euros for one kilo plus postage, purchase by emailing **info@karl-grimm.com**. It's the most aesthetically pleasing thread I've ever used, and both the copper and silver variants are soldering iron-friendly, unlike most other threads on the market. However, it can be hard to get hold of, plus it only comes in fairly large quantities. It also tangles easily and can be brittle, so it doesn't work in sewing machines, and you have to really pay attention when stitching with this thread. Yes, this thread can be a little tricky to obtain and use, but for a special project, it is absolutely worth the effort.

> You could use more conductive thread to **hand-embroider additional trigger points to the tentacle**

You can also choose to augment your tentacle with a little code. The Bare Conductive Touch Board is compatible with Arduino. Here's how to get started. First up, download the Arduino IDE or make sure you're currently running the most up-to-date version. You can't use the Arduino Web Editor with this board. Next, download and run the Touch Board installer from the Bare Conductive website (**hsmag.cc/PMeA1A**). This will add all the relevant files and directories to the Arduino IDE.

Once the installer has done its job, open up the Arduino IDE and head to File > Sketchbook > Touch Board Examples to check out the example code you can play with. Once you have something that you'd like to try out, connect your board to your computer using the micro USB cable and turn it on. Head to Tools > Board then Tools > Port to select the Touch Board, then upload your code and play! □

High Quality Camera: Flash photography using an LED

Add an LED flash to shoot images in low light

The Raspberry Pi Camera Module or HQ Camera works really well in good lighting conditions, but what if there's less light available? Here, we show you how to set up a simple LED flash, which will be triggered each time you take a photo, using the picamera Python library. We also take a look at how to shoot better images in low light when you are not using a flash.

01 Download device tree source

Before we can wire up a flash, we need to configure a GPIO pin to use for it. This will then be triggered each time we capture a still using picamera with the flash mode set to on. To do this, we need to edit the VideoCore GPU default device tree source. First, install device tree compiler with:

```
sudo apt-get install device-tree-compiler
```

Then grab a copy of the default device tree source with:

```
wget https://raw.githubusercontent.com/
raspberrypi/firmware/master/extra/dt-blob.dts
```

02 Edit the device tree source

Edit the file using your favourite text editor, such as nano:

```
sudo nano dt-blob.dts
```

You'll need to find the correct part of the code for the Raspberry Pi model you're using; for instance, the part for Raspberry Pi 4 is found under `pins_4b {`.

Here you'll find `pin_config` and `pin_defines` sections. In the `pin_config` section, add a line to configure the GPIO pin (we're using GPIO17) that you want to use for the flash:

```
pin@p17 { function = "output"; termination =
"pull_down"; };
```
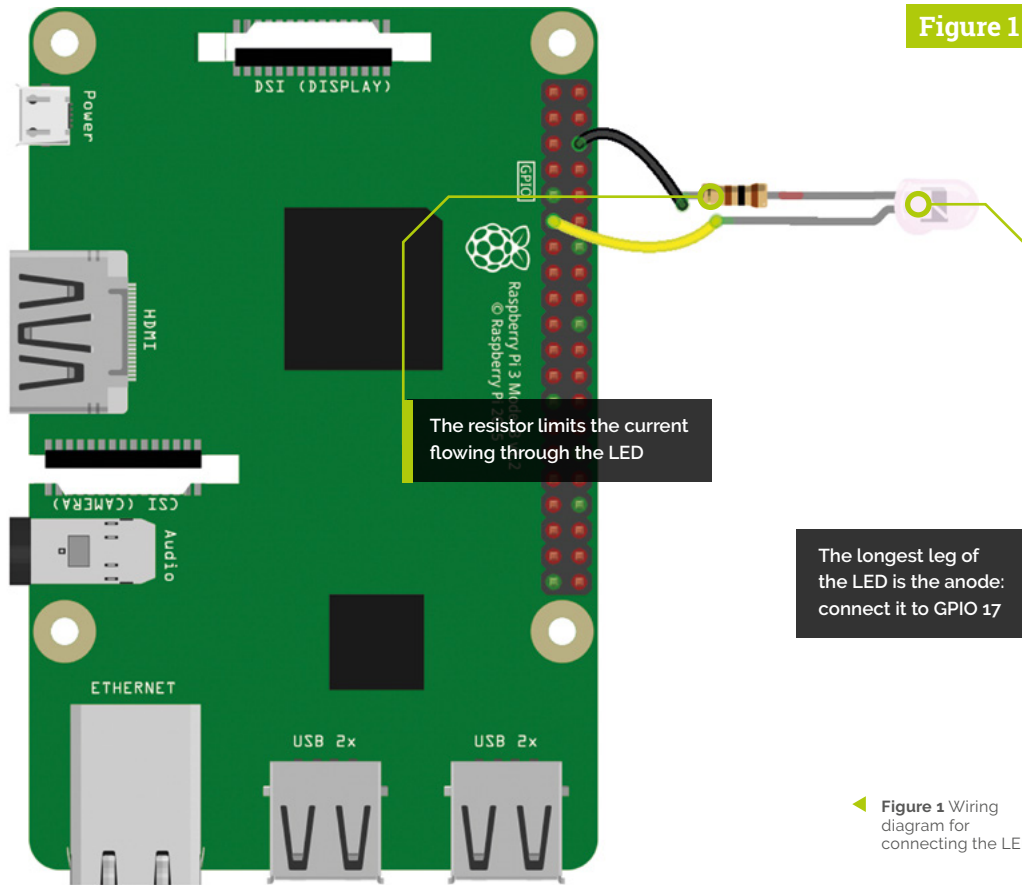
> ❝ Before we can wire up a flash, we need to configure a GPIO pin to use for it ❞

03 Enable flash

Next, we need to associate the pin we added with the flash enable function by editing it in the `pin_define` section. We simply change absent to internal and add a line with the pin number, so it looks like the following:

```
pin-define@FLASH_0_ENABLE {
    type = "internal";
    number = <17>;
};
```

Note that it's the `FLASH_0` section that you need to alter: `FLASH_1` is for an optional privacy LED to come on after taking a picture, but we won't bother with that.

The resistor limits the current flowing through the LED

The longest leg of the LED is the anode: connect it to GPIO 17

◀ **Figure 1** Wiring diagram for connecting the LED

04 Compile the blob

With the device tree source updated, we now need to compile it into a binary blob, using the following command in a Terminal window:

```
dtc -q -I dts -O dtb dt-blob.dts -o dt-blob.bin
```

This should output nothing. Next, you need to place the new binary on the first partition of the microSD card. In the case of non-NOOBS Raspbian installs, this is generally **/boot**, so use:

```
sudo cp dt-blob.bin /boot/
```

In you installed Raspbian via NOOBS, however, you'll need to do the following instead:

```
sudo mkdir /mnt/recovery
sudo mount /dev/mmcblk0p1 /mnt/recovery
sudo cp dt-blob.bin /mnt/recovery
sudo umount /mnt/recovery
sudo rmdir /mnt/recovery
```

To activate the new device tree configuration, reboot your Raspberry Pi.
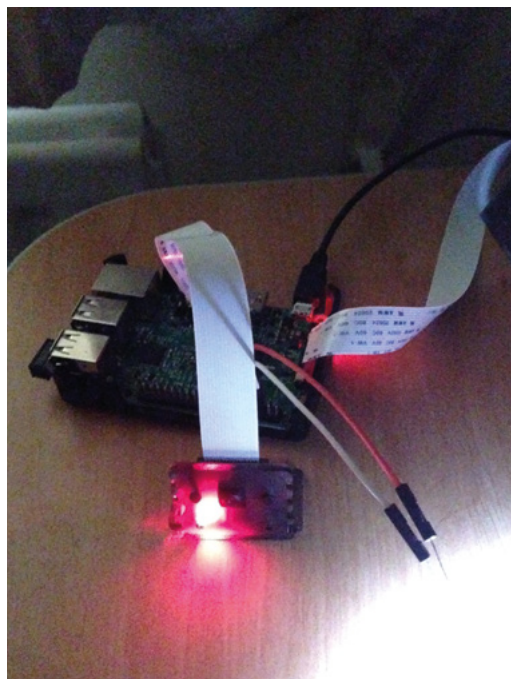
▲ Wire the white LED to GPIO 17 and GND via a low-ohmage resistor
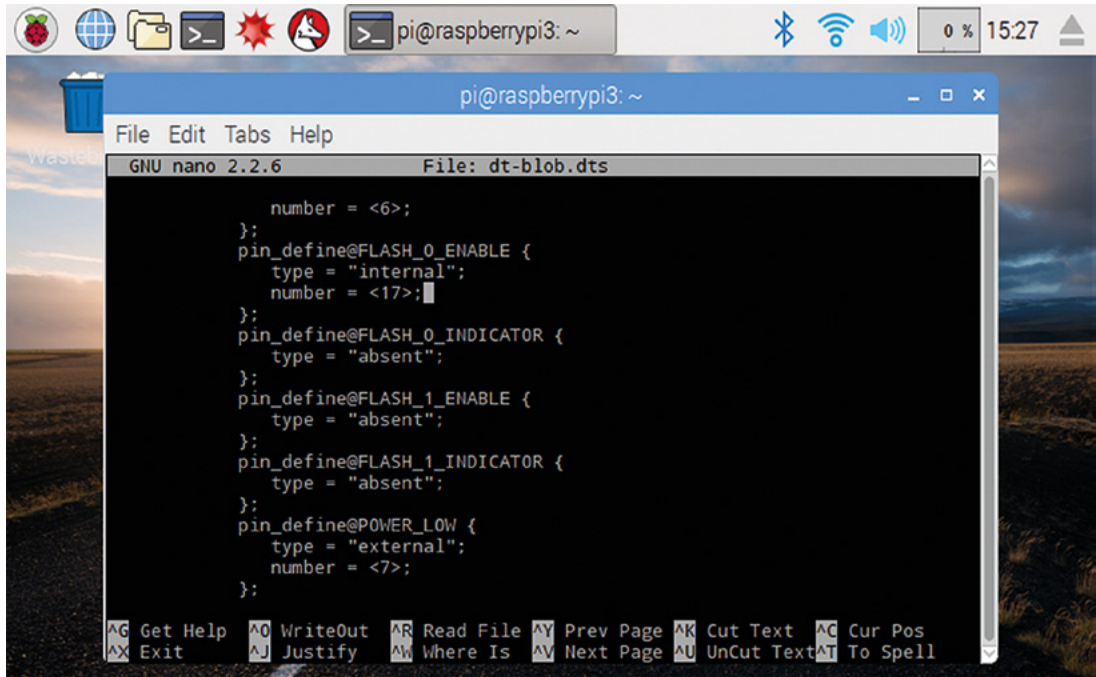
▶ You need to edit the device tree source to enable a GPIO pin for the flash

05 Wire up the LED

Connect a white LED – we used a 5 mm one – to your Raspberry Pi as in **Figure 1** (previous page). The LED's anode (long leg) is connected to our flash-enabled pin, GPIO17. To be sure of the LED not burning out from excess current, you should add a low-ohmage resistor (such as 100 Ω) between the LED's cathode (short leg) and Raspberry Pi's GND pin. Depending on the maximum forward voltage of your LED (ours was 3.2 V), you may want to choose a resistor with a different ohmage, but it's always best to use one to be safe.

If you want to use higher-powered or multiple LEDs, you'll have to think about powering them via a suitable driver circuit, with a transistor wired to the flash pin. You may also need a separate power supply. Note that, due to the Raspberry Pi Camera's rolling shutter, only an LED or equivalent flash is suitable: you can't use a xenon flash. Alternative flash/lighting methods include NeoPixel sticks and the LISIPAROI light ring.

06 Test it out

With the LED connected, we can now test out our flash with a short Python program. In Thonny, create a new file and enter the code from **listing1.py**. The `camera.flash_mode = 'on'` line

sets the flash to trigger when we issue the capture command below; the LED will light up briefly before the image capture, to enable the camera to set the correct exposure level for the extra illumination, before the flash proper is triggered. If you want the flash to trigger automatically only when it's dark enough, you can change the penultimate line of the code to `camera.flash_mode = 'auto'`.

> ❝ The LED will light up briefly before image capture, so the camera can set the correct exposure level ❞

07 Low-light photography

In low-light scenarios where you don't want to use a flash, you can improve capture of images using a few tricks. By setting a high gain combined with a long exposure time, the camera is able to gather the maximum amount of light. Note that since the `shutter_speed` attribute is constrained by the camera's frame rate, we need to set a very slow frame rate. The code in **listing2.py** captures an image with a six-second exposure time: this is the maximum time for the Camera Module V1 – if you

▲ Even a single white LED can provide illumination for close-up photography

have a v2 Camera Module, it can be extended to ten seconds, or much longer for an HQ Camera. The frame rate is set to a sixth of a second, while we set the ISO to 800 for greater exposure. A pause of 30 seconds gives the camera enough time to set gains and measure AWB (auto white balance).

Try running the script in a very dark setting: it may take some time to run, including the 30-second pause and about 20 seconds for the capture itself. Note: if you're getting a timeout error, you may need to do a full Raspbian upgrade with `sudo apt update` and `sudo apt dist-upgrade`.

The particular camera settings in this script are only useful for very low light conditions: in a less dark environment, the image produced will be heavily overexposed, so you may need to increase the frame rate and lower the shutter speed accordingly.

If the image has a green cast, you'll need to alter the white balance manually. Turn AWB off with `camera.awb_mode = 'off'`. Then set the red/blue gains manually; e.g. `camera.awb_gains = (1.5, 1.5)`. 🅼

▲ Using a long exposure, you can shoot stills in very dark settings

listing1.py

> Language: **Python 3**

```
001.  import picamera
002.
003.  with picamera.PiCamera() as camera:
004.      camera.flash_mode = 'on'
005.      camera.capture('foo.jpg')
```
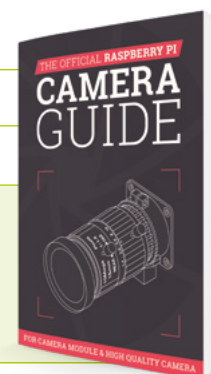
listing2.py

> Language: **Python 3**

```
001.  from picamera import PiCamera
002.  from time import sleep
003.  from fractions import Fraction
004.  # Set a framerate of 1/6fps, then set shutter
005.  # speed to 6s and ISO to 800
006.  camera = PiCamera(resolution=(1280, 720),
007.  framerate=Fraction(1, 6))
008.  camera.shutter_speed = 6000000
009.  camera.iso = 800
010.  # Give the camera a good long time to set gains and
011.  # measure AWB (you may wish to use fixed AWB
012.  instead)
013.  sleep(30)
014.  camera.exposure_mode = 'off'
015.  # Finally, capture an image with a 6s exposure. Due
016.  # to mode switching on the still port, this will take
017.  # longer than six seconds
018.  camera.capture('dark.jpg')
```

The Official Raspberry Pi Camera Guide

For further tutorials on how to use your HQ Camera or Camera Module, take a look at our new book, *The Official Raspberry Pi Camera Guide*. Its 132 pages are packed with essential info and a range of exciting projects.
magpi.cc/cameraguide

HackSpace
TECHNOLOGY IN YOUR HANDS

FIELD TEST

HACK | MAKE | BUILD | CREATE

Hacker gear poked, prodded, taken apart, and investigated
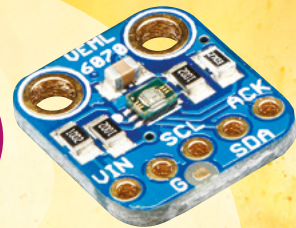
ONLY THE BEST

It's bright! But how bright?

The best sensors for measuring light

By **Marc de Vinck**   @devinck

Anyone who has played around with electronics has inevitably come across a photoresistor, or light-dependent resistor (LDR), at some point. They are a staple in designs that create variable musical tones based on the amount of light that you might block with your hand, control LEDs based on ambient light conditions, or are even used to track the sun in a solar power array. They are a lot of fun to use, but these classic components are also problematic for a few different reasons.

> **They are a lot of fun to use, but these classic components** are also problematic for a few different reasons

An LDR typically decreases its resistance based on the amount of light that hits the surface. More light equals less resistance. You can easily imagine how you might implement a variable resistor into a project, for fun or as a necessity. But, as mentioned earlier, this inexpensive little passive component has a few issues. Firstly, they are wildly inaccurate,

and secondly, they typically contain cadmium sulphide, a substance that has heavy restrictions for use in Europe due to the Restriction of Hazardous Substances Directive (RoHS) implemented in the early 2000s.

Fortunately, there are alternatives to the typical inaccurate and cadmium-based LDR. There are also many different ways of measuring light, some with added functionality too! And that's what we'll be looking at in this Best of Breed. Being able to measure and react to light is a critical function of many circuits, and I'm glad there are other more accurate, and RoHS-friendly, devices and technologies out there in the world.

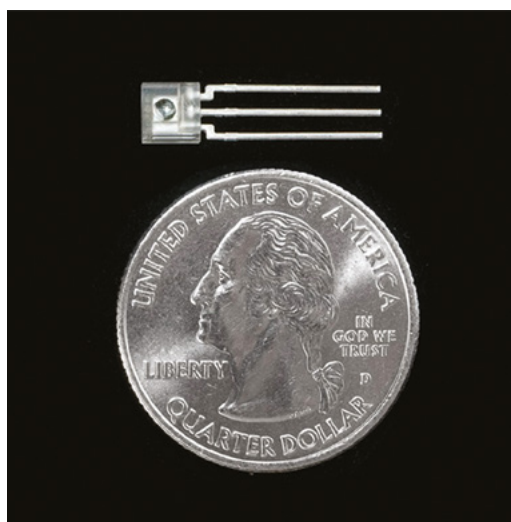# Light-to-Frequency Converter vs Photo Transistor Light Sensor

SPIKENZIELABS ◆ $2.95 | spikenzielabs.com   **ADAFRUIT** ◆ $0.95 | adafruit.com

The TSL235R light-to-frequency converter, available at SpikenzieLabs, combines a silicon photodiode and a current-to-frequency converter into one convenient package. It outputs a square wave, at 50% duty cycle, at a frequency that is directly proportional to the light that it senses.

You can power the sensor with a voltage between 2.7 V and 5.5 V, and it will output the square wave signal. No other components are needed. And since it's a digital output, it's really easy to integrate into your next Arduino or Raspberry Pi project. If you are looking for a nice RoHS alternative, without the need for additional circuitry, this is a good choice.

Right
Light goes in, square waves come out

VERDICT

Light to Frequency Converter

An interesting alternative to an LDR.

10/10

Photo Transistor Light Sensor

**A great RoHS alternative light sensor.**

10/10

The Photo Transistor Light Sensor from Adafruit is a simple two-lead replacement for a classic LDR that's RoHS-compliant and easy to use. When light hits the Photo Transistor, it induces a current to flow from the long lead to the short lead of the component.

To use this component, you simply supply 3–15 V to one lead of the sensor and connect a 1 kΩ – 10 kΩ resistor to ground on the other lead. When light hits the sensor, which has a built-in IR filter, you will get an increase in voltage. No light, no voltage. Depending on your needs, you can adjust the resistor in the circuit to get the specific range of voltages required. It's a simple replacement for the traditional LDR. →

Right
It may look like an LED, but it's a photo transistor
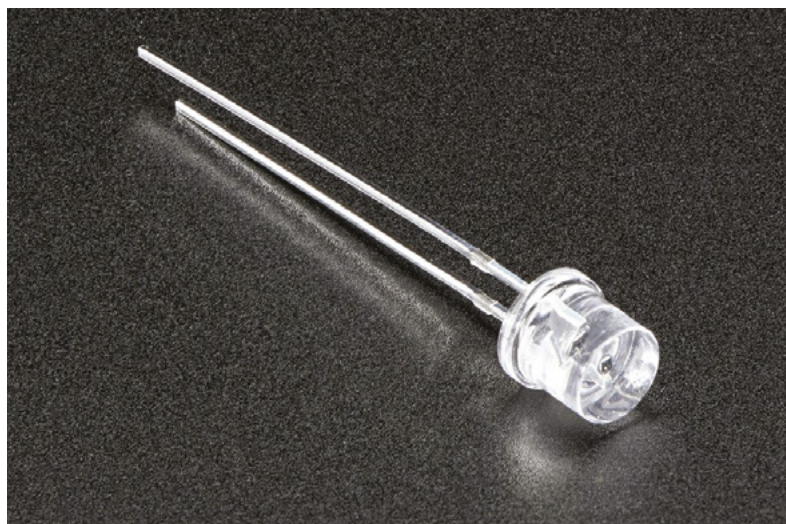
Adafruit VEML7700 Lux Sensor

ADAFRUIT ◆ $4.95 | adafruit.com

T he Adafruit VEML7700 Lux Sensor – I²C Light Sensor is a simple lux sensor that makes for a perfect addition to your next microcontroller project. A typical light sensor just gives you analogue, or sometimes digital, feedback. A voltage based on the light. But what does that mean? This Vishay-based lux sensor takes the light value and calculates the lux, or amount of luminance. It's a standard measurement used in many scientific fields. It's particularly good when you need more than one sensor, as each sensor's output would be based on lux and not just a random resistance value.

The VEML7700 Lux Sensor has a wide, 16-bit dynamic range for ambient light detection. It can sense from 0 lux to about 120 kilolux, with a resolution as small as 0.0036 lx/ct. Couple all that accuracy and range with the available Arduino and Python library, and you'll see why this is the lux sensor to use in your next project.
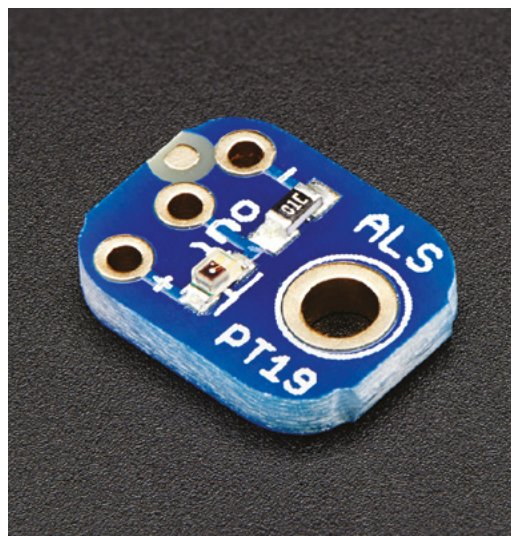
VERDICT

Adafruit VEML7700 Lux Sensor

An inexpensive and great little sensor breakout board.

10/10

Adafruit ALS

ADAFRUIT ◆ $2.50 | adafruit.com

W ant a simple, RoHS-compliant, and affordable alternative to a cadmium-based photoresistor? Then this diminutively small ALS-PT19 Analogue Light Sensor Breakout board from Adafruit just might be for you. Use it as a replacement for non-RoHS components, especially where space is constrained. Simply connect the sensor to GND and +2.5V – 5.5V to power it and start taking measurements from the analogue output pin. When it sees light, the voltage will go up. If you need to easily sense light in the typical human eye range, this is a decent choice.

Above ◩
Precise light level sensing in one small package

Left ◆
Like an LDR, but better for the environment
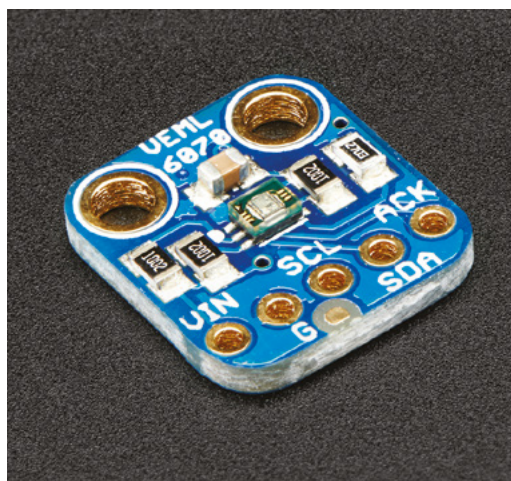
VERDICT

Adafruit ALS

A great replacement for a non-RoHS light sensor.

8/10

Adafruit VEML6070 UV Index Sensor

ADAFRUIT ◈ $5.95 | adafruit.com

But what if you want to measure nonvisible UV light? Then that's where the Adafruit VEML6070 UV Index Sensor comes into play. This board features a Vishay sensor that has a UVA light sensor and an I²C-controlled ADC, making it a perfect addition to your next microcontroller project. And although you don't get some of the added features of other, more costly sensors, this one is really simple to use. You will need to solder some header pins on, but thankfully they are included. Head over to the website for a detailed tutorial, including code, for using this handy little UV sensor.

Left ◈
This can see UV light that's invisible to the human eye

VERDICT

Adafruit VEML6070 UV Index Sensor

A good choice for measuring UV light.

9/10
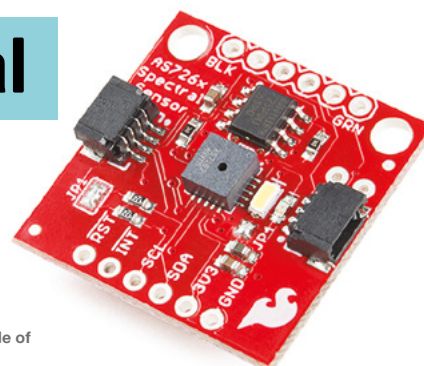

SparkFun NIR Spectral Sensor Breakout

SPARKFUN ◈ $25.95 | sparkfun.com

Right ◈
Light can help you understand what material something's made of

This one is for some of the more advanced tinkerers out there looking for a specialised spectral sensor capable of measuring near infrared (NIR) light. The SparkFun Spectral Sensor Breakout board allows anyone to experiment with infrared light spectroscopy. But what is infrared spectroscopy? It's the science of measuring the light spectrum produced when infrared light is either absorbed, emitted, or reflected on a substance. It's accomplished by having a known light source, built into the board, light up a test sample, and the sensor reads the reflected light.

Light spectroscopy is useful in measuring things like the photosynthetic light efficiencies in plants, and a lot more. Just don't confuse this with mass spectrometry – that's a more complicated science. And no, there aren't any breakout boards for mass spectrometry… yet! If your needs don't fall within the infrared range, they have a visible light version too. See the SparkFun website for more about the various Spectral Sensor Breakout boards they have available.

VERDICT

SparkFun NIR Spectral Sensor Breakout

When you need a spectral sensor, this is a good start.

8/10

LTR-559 Light and Proximity Sensor Breakout

PIMORONI ◆ **$9.10** | pimoroni.com

T
he LTR-559 Light and Proximity Sensor Breakout board from Pimoroni is capable of reading a wide dynamic range of light, from 0.001 to 64,000 lux, as well as proximity at a short range of about 5 cm. With that much of a range, you are capable of a lot of detailed sensing.

The board features an I²C interface for easy communications to your microcontroller, and is 3.3 V or 5 V compatible. The PCB is designed so that you can add a male header pin to the board and plug it directly into the bottom left five pins of a Raspberry Pi for quick prototyping. And, if you are using the Pimoroni Breakout Garden system, it's a simple plug-and-play installation. Check out their website for more information, and to grab the compatible Python library that will get you up and running fast. □

> **With that much of a range,** you are capable of a lot of detailed sensing
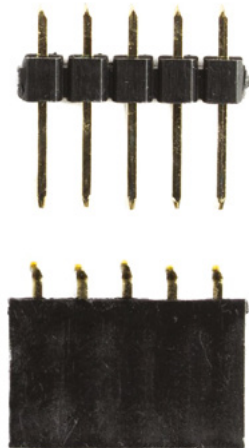
Above ◈
This can tell how bight something is and how far away it is

CODE
THE
CLASSICS

VOLUME 1

CODE
THE
CLASSICS
VOLUME 1

Brimble
Crookes
Gillett
Malone
Tracey
Upton²

Raspberry Pi
PRESS

REVIEW
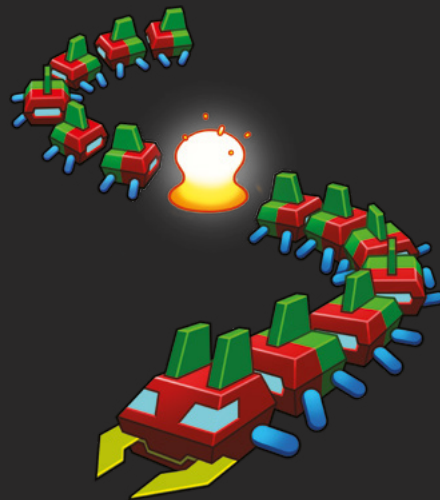
Formit 3 in 1 Universal Sheet Metal Machine

Cut and shape metal with one machine

WARCO ◆ £236.25 | warco.co.uk

By **Jo Hinchliffe**   🐦 @concreted0g

Warco is a UK company offering a range of machine shop tools and is well-known for selling lathes, milling machines, pillar drills, and more. We were interested in the Formit range of tools which offer a three-in-one solution for bending, shearing, and rolling thin sheet metal, and also wire materials.

The Formit range has a range of sizes from 305 mm to 1000 mm, and also a 'Mini Formit' which can handle 200 mm wide materials. This review is for the 305 mm version. The Formit is a heavy object at just under 50 kg, and it arrived well-boxed and strapped to a pallet. For us, it was OK for one person to carry the box to the workshop, but others might need to arrange for a helping hand.

The Formit is largely assembled, with the rear guide rails, some of the adjustment screws, and the main handle needing attaching. However, and at no detriment to Warco, we are used to machine tools requiring some cleaning up and commissioning on arrival, and this was true in the case of the Formit. Similar to many machine tools, it arrived well-covered in packing grease and required a partial strip-down and clean. Out of the box, we were generally pleased with the weight and quality of the castings, with the exception of the front left-hand foot which appeared to have not been cast correctly. It's only cosmetic, and there is certainly enough metal there to be strong enough to bolt through and hold down, but it's one mark off in the verdict. Everyone has a different approach for cleaning off machine tool packing grease; we prefer paraffin and a cloth,

and we were pleased how well it cleaned. There were no oxidised patches on the machine, and it all looked OK. We quickly found some M10 steel nuts, bolts, and washers and mounted the Formit on a sturdy workbench.

The handle can be attached to either side of the machine – it sits in a grooved holder and a wing bolt simply traps the handle in any position you like. This is useful, as you might want the handle in the middle when using the rollers, but might want it at one end when using the shears or the bending aspects. Out of the box, our Formit would only rotate a small amount with the jaw of the shear hitting the surface of the bed. This is adjustable, of course, but it took a moment to work out how. We needed to undo the block on the right-hand side of the bed to access the bed securing bolt on that side. Having slackened off the bed securing bolts on either side, there are some adjustment bolts that sit horizontally, with large washers that connect to a groove in the machine bed. Tightening or loosening these pushes or pulls the bed backwards and forwards.

Having got the shear clearing the bed, we did some test cuts. This Formit is designed to be able to handle mild steel up to 0.8 mm thick, and aluminium up to 1.2 mm thick. Using the shear confirmed this – we easily cut through a 25 cm wide sheet of 1 mm thick aluminium with no problem. As a sneaky experiment, we tried some 1.2 mm mild steel sheet and, indeed, this was beyond the capacity it could handle. However, some 0.8 mm mild steel sheet cut successfully, albeit with considerable effort on the handle. Incidentally, we also discovered that the packing strapping off the pallet we received was 0.8 mm thick mild steel, so this can make some useful scrap test pieces. We were very impressed with how the shear could cut very thin sheet with very little marking or buckling of the stock. We could trim drink can aluminium extremely neatly, for example.

The bending section consists of an array of vee press tools above a long single vee slot. The pressing tools are inserted and clamped in position; you can rearrange them so that you can do bends with a gap between bends – extremely useful for making folded metal boxes. Again, the bending section worked extremely well across a range of materials and is quite straightforward to use. The instructions state that it's limited to 90-degree bends, but we found that with too much force, it will produce more than 90 degrees. It's definitely worth practising with some scrap to get the feel of how to repeatedly make accurate 90-degree folds.

The rollers are hidden under the yellow cover which pivots out of the way neatly. Obviously, when using the shear or the bending brake, the rollers will also move and, as such, it's a good idea to keep them covered to reduce the risk of accidental entanglement. The instructions supplied give a good overview of how to use the rollers, and how to increase the tightness of the curve produced. With this type of roller system, you always end up with a small, flat section at the start of the roll, so it's worth again practising with some scraps to dial in your approach before making a critical-sized component with them. ▢

> **Some 0.8 mm mild steel sheet cut successfully, albeit with considerable effort on the handle**

Above
A collection of items folded on the Formit, made from a variety of steels and aluminium sheets

Left
Whilst we may need more practice to increase accuracy, it's easy to get started rolling curves and tubes on the Formit

Below
We were very impressed with the shear tool. Here, we see a 0.8 mm sheet of aluminium cleanly sheared. Note that there are no imperfections in the cut piece or the stock after shearing
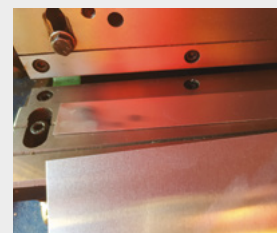
VERDICT

An excellent tool for making small metal parts, with all three functions working well.

8/10

3D-printed Landspeeder Kit Card

A flat-packed toy to share with family and friends

FIXUMDUDE | thingiverse.com

By **Ben Everard** 🐦 **@ben_everard**

Most of the time, we want our 3D prints to come off the print bed as near complete as possible. With some clever design, you can even print multi-part mechanical designs in one go. However, there's a whole school of design of flat-packed 3D printables. The main use of these is to make them fit in cards. The designs are made up of several little bits that 'pop' out of a frame and then connect together. They make great gifts, and thanks to their low Z-height, they print quickly.

Search for 'kit card' on your favourite 3D model repository, and a wide range will pop up. We took a look at one of the newest additions to this selection, the Landspeeder Kit Card by fixumdude on Thingiverse (**thingiverse.com/thing:4592209**).
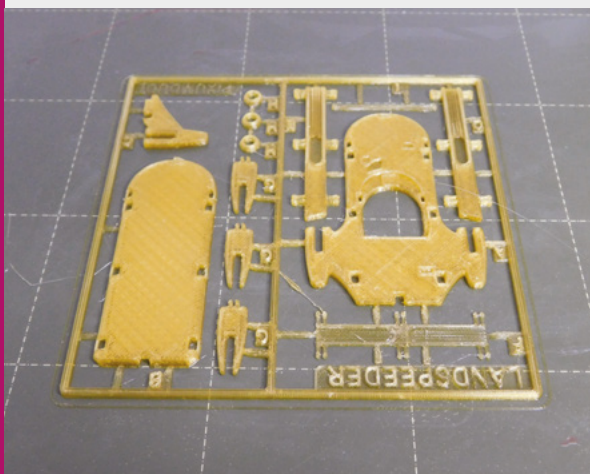
On our Prusa i3 MK3S, this prints in about 90 mins. We printed it in Fillamentum CPE Morning Sun (because we're testing out some polycarbonate for a feature next month), but it prints equally well in PLA, and should work in most plastics.

Once printed, the parts snap out of place. You can put this together with no tools, but flush cutters, or a sharp knife, let you trim off any residual plastic from the break. There's a PDF of instructions for assembly as there are quite a few steps – it's not particularly complicated, but if you tried to do it without these, you'd probably struggle.

We've had great fun with this and other 3D-printable kit cards over the years. As winter approaches with all its various festivals, it's a great time to share your maker skills with those you love, especially as we may not be able to spend as much time with people as we'd like this year. ▫

VERDICT

A fun way of sharing your 3D printing with friends.
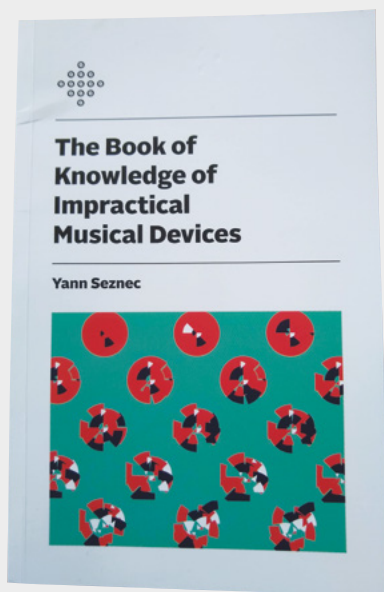
9/10

The Book of Knowledge of Impractical Musical Devices

YANN SEZNEC ◆ $15 | Self-published

By **Ben Everard** ◎ @ben_everard

This book is part of an art project exploring the relationship between technology and our perception of sound. Seznec details three musical devices – one called 'A day that will never happen again' that creates a new audio clip for each day, one called 'Here you are, you are here' that plays music based on a GPS lock on your current location, and one called 'Everything you love will one day be taken from you' that records a noise, then slowly destroys it as it's played back.

The code for all the projects is on GitHub, and none of them is particularly complex to build should you wish, though perhaps the point isn't that you recreate these projects, but use them to inspire your own weird and wonderful creations. The book mostly describes the inspiration behind them, rather than the process of building the machines.

Our relationship with technology is complex, and things are often created purely for their utility without much thought of the ethical and emotional consequences. This project, in some way, reverses that – plenty of thought has gone into their ethical and emotional consequences, but perhaps little into their utility.

Does this matter? Probably. Does it matter at the level of things ordinary makers build? Maybe not, but at 46 pages, it's a quick read and left us brimming with ideas for how to play with the way we interact with technology. □

VERDICT

It's quirky and thought-provoking about our relationship with technology.

9 /10

next month

issue

#37

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