MAKE | **BUILD** | HACK | **CREATE**

132 PAGES OF MAKING

HackSpace

TECHNOLOGY IN YOUR HANDS

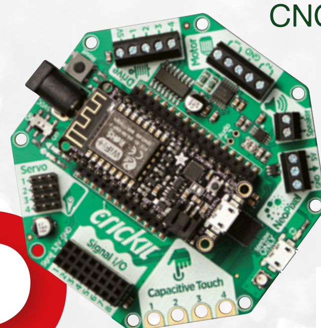
hsmag.cc | December 2019 | Issue #25

BLUETOOTH

Wireless data with CircuitPython

3D DESIGN

Create models for your CNC router



Dec.2019
Issue #25 £6

MAKER CHRISTMAS

The best toys, tools, and trinkets for your hacker Christmas list

MUSIC MACHINES

Sam Underwood on the science of sound

3D PRINTING

Making your prints shine!

BRAZING CANDLES **MAKING MUSIC** DRILLING

Welcome to HackSpace magazine

I admit it; I'm a hard person to buy presents for. My interests can be so obscure that esoteric doesn't even come close to describing them – I have a collection of LEDs, for example, that covers almost every form of WS28XX, and a wide variety of others (my personal favourites are the selection of auto-flashing LEDs). However, we've tried hard to come up with a selection of Christmas presents this month that every maker will enjoy. If you're like me and loved ones struggle to buy for you, perhaps leave this issue lying around the house, with handily placed Post-it notes.

If you're still preparing the decorations for Christmas, you might want to take a look at Keith Kelly's electric candle. Not everyone will want to go to the lengths he has, but there are some great tips there that even simple candles will benefit from. Flip to page 52 for more details, or turn the page to find a full list of all the maker awesomeness we've got going on this month.

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Editor ben.everard@raspberrypi.org

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

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PAGE 50
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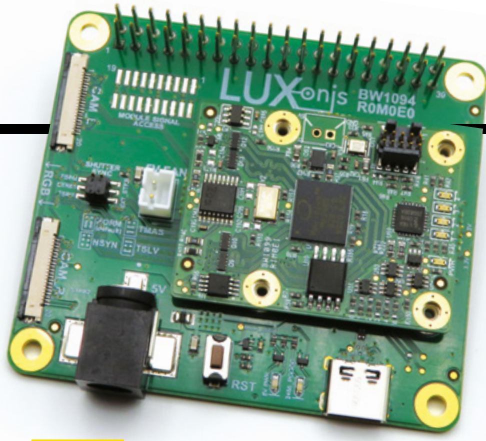
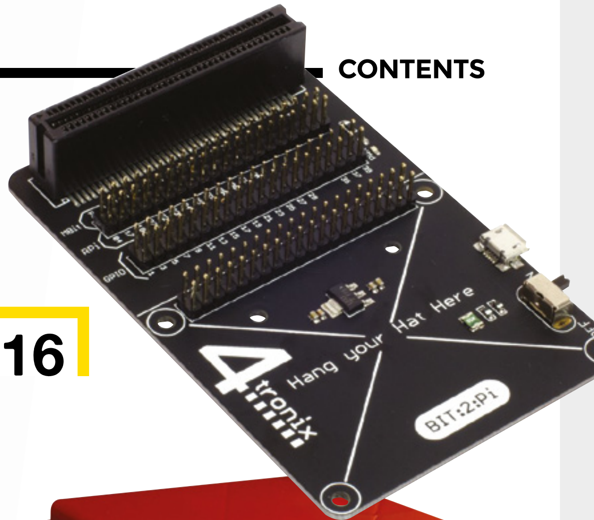
Contents

18



26



116

Interview

Sam underwood

62 Why digital modular synths are last year's model

Direct from Shenzhen

Chainsaw wheel

114 If you love danger, get one of these death wheels

122

81 FORGE

113 FIELD TEST

From Dirt To Space

By **Richard Kraaijenhagen et al** hsmag.cc/4KPbYZ

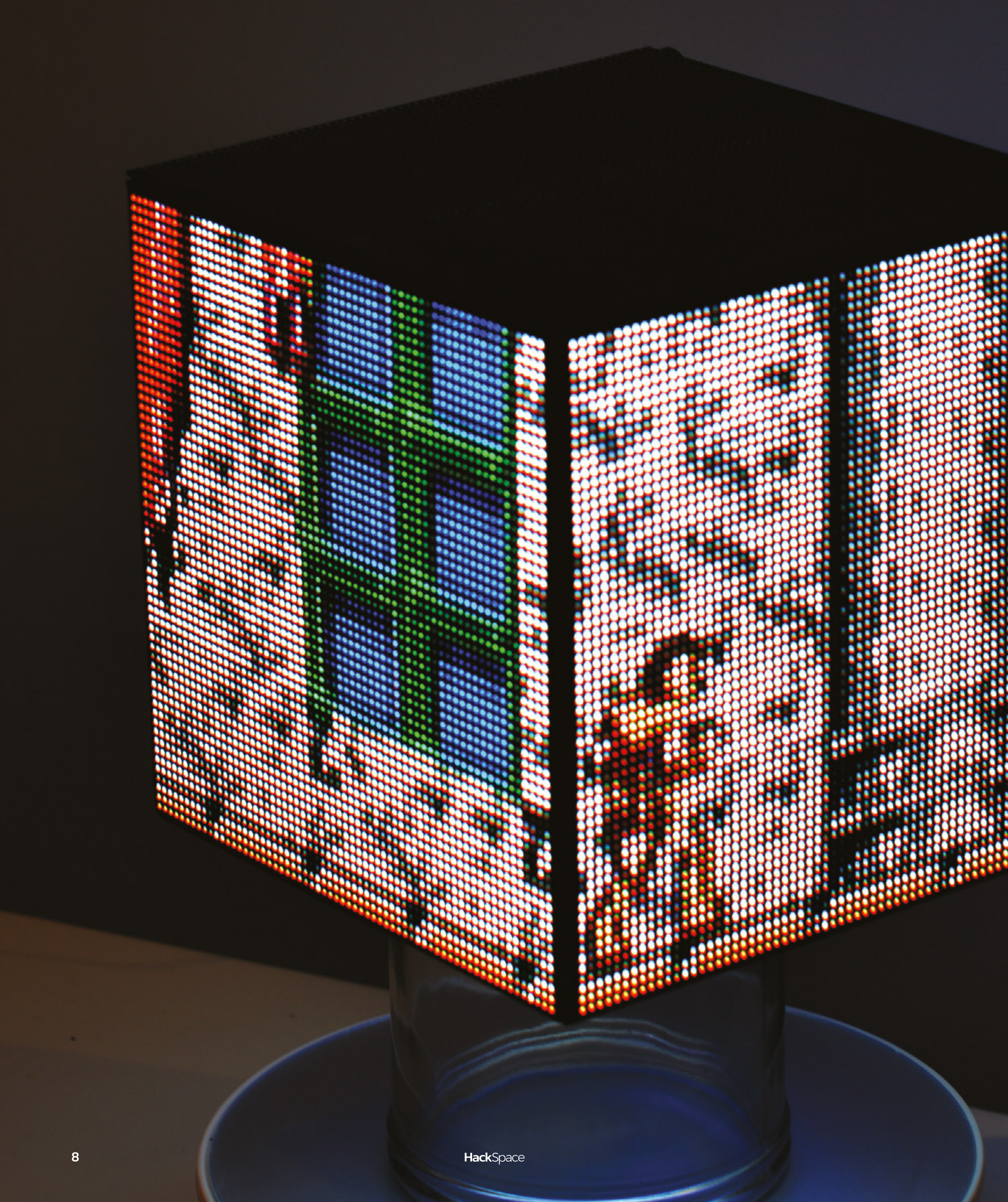
From Dirt To Space is a project organised by three maker groups in the Netherlands: RevSpace, Hack42 in Arnhem, and SparkShack. The project's aim is to make iron from locally found bog ore (an especially poor-quality form of iron ore) and get the resulting metal object into space.

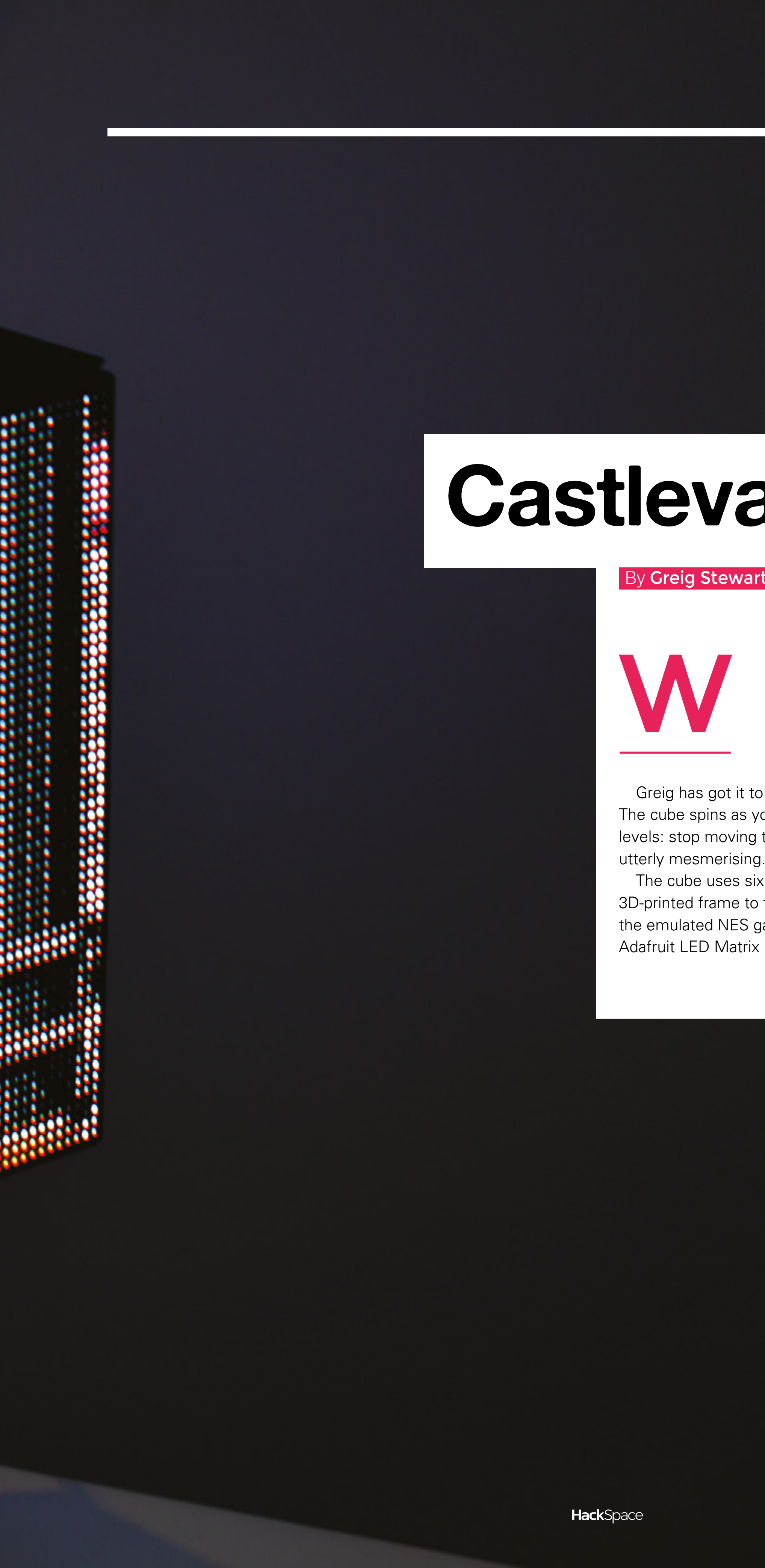
The team have built their own portable version of a blast furnace, which reaches temperatures of up to 1200°C. All it is is a chimney of bricks, charcoal, and iron ore, plus two leaf blowers to keep up a steady flow of air, and to make sure the charcoal burns hot enough to melt iron.

The team have made three attempts so far, learning and refining the process, and attempt number four is due to take place at the end of April 2020.

Right
Iron Age people didn't have access to leaf blowers, but that's not the point

Credit
Richard Kraaijenhagen, for the Joint task force of SparkShack, RevSpace, and Hack42





Castlevania cube

By Greig Stewart

Thereminhero.com

We're suckers for shiny stuff at HackSpace Towers, and so we love this beautiful, skinny, interactive LED matrix. Its creator, Greig Stewart, has released several videos showing animations on its surface, but we think the best use for it is as a games device.

Greig has got it to play the ancient Nintendo classic Castlevania. The cube spins as you move the game's protagonist through the levels: stop moving the sprite, and the cube stops spinning. It's utterly mesmerising.

The cube uses six Adafruit 64×64 LED matrices, mounted on a 3D-printed frame to form a cube. There's a Raspberry Pi 4 to play the emulated NES game, which is joined up to the LEDs with an Adafruit LED Matrix Raspberry Pi Bonnet.

Left
See Castlevania played on a spinning interactive cube here: hsmag.cc/DCTXRZ

Cheeseborg

By **Mitchell Riek, Taylor Tabb, and Evan Hill** hsmag.cc/p7mVL8

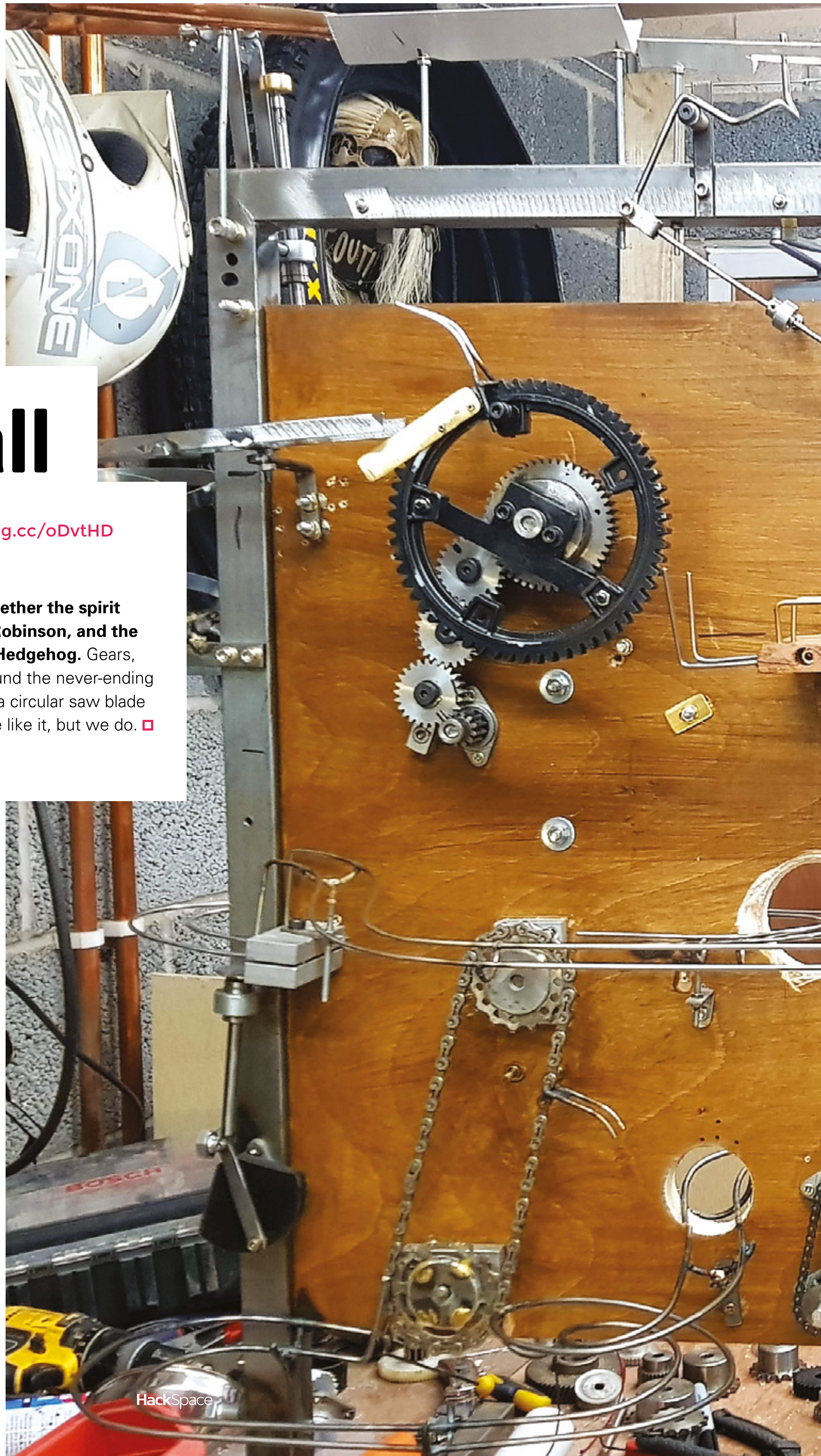
The cheese toastie is part of the staple diet of students, full as it is with delicious salt, fat, and beer-absorbing carbohydrate. Three students at Carnegie Mellon University in the USA have taken this one step further with an automatic cheese toast-making machine.

A vacuum system lifts a slice of bread into place, followed by a slice of cheese and another slice of bread; the assembled sandwich is pushed into a grilling machine. Then, when it's done, a second lever pushes the finished snack into a delivery slot. It even squirts butter onto the surfaces in contact with the heated grill.

The mechanical parts of this robotic sandwich maker are controlled by an Arduino Mega, with voice activation enabled by Google Assistant running on a Raspberry Pi. In an extra special twist, the students have programmed the Cheeseborg such that you have to say 'please' when you ask for a grilled cheese sandwich or it won't work – a sensible way to ensure that when the robots rise up, these three students at least will be spared. You can see the contraption in action at **hsmag.cc/p7mVL8**

Right I, for one, welcome our robotic chef overlords


EXIT
Cluster Available



Mech Ball

By Steve Sherwin

hsmag.cc/oDvtHD

This piece of kinetic art pulls together the spirit of Wallace and Gromit, Heath Robinson, and the Spring Yard Zone of Sonic the Hedgehog. Gears, levers, and cams propel balls around the never-ending track. For good measure, there's a circular saw blade attached. We don't know why we like it, but we do.

Right
There's more of Steve's work at: hsmag.cc/LmrzNI

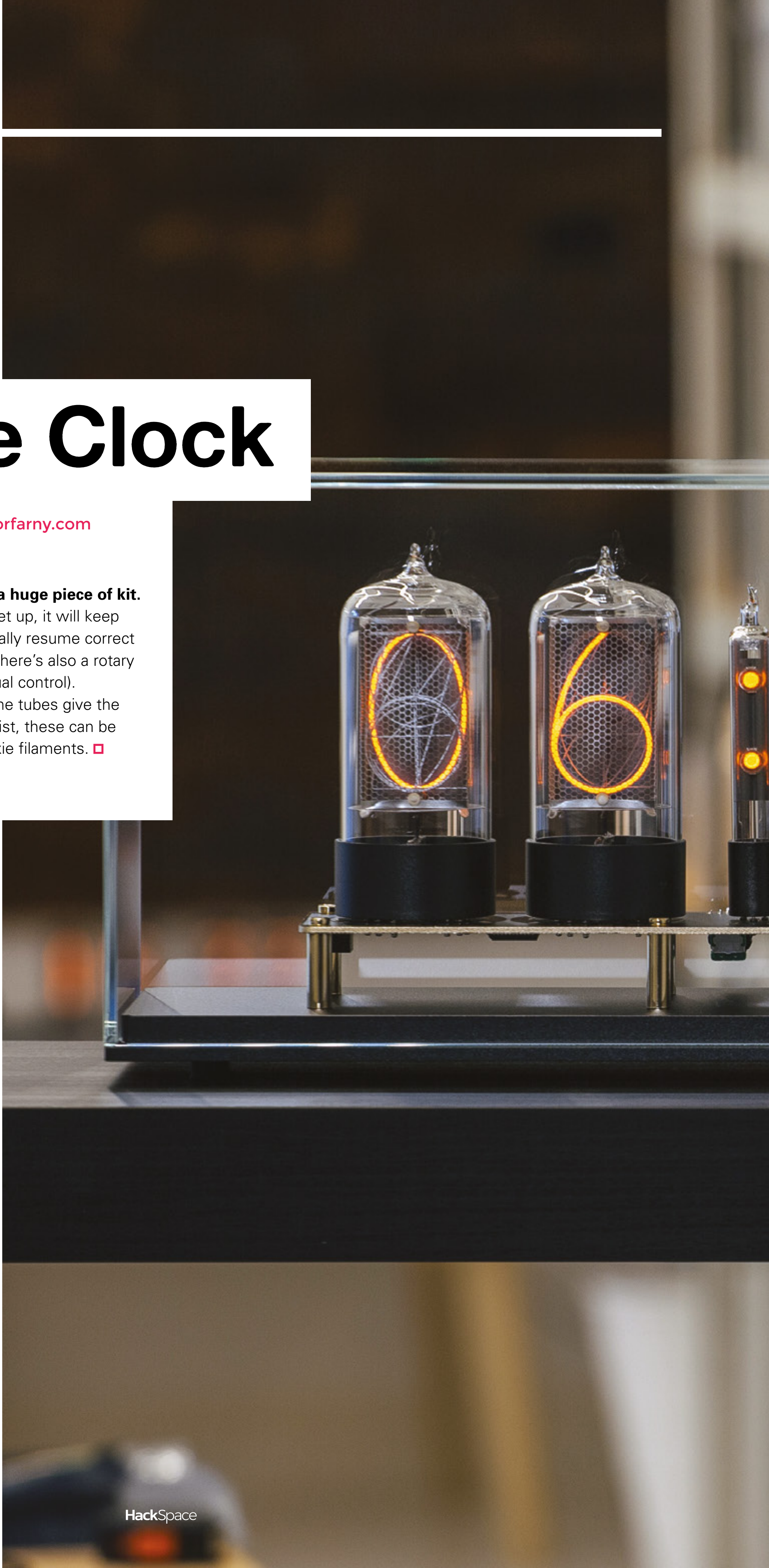
Zen Nixie Clock

By Dalibor Farny

daliborfarny.com

This clock by Dalibor Farny is a huge piece of kit. It syncs via WiFi, so once it's set up, it will keep the correct time and automatically resume correct time after being switched off (there's also a rotary controller on the back for manual control).

RGB LEDs mounted under the tubes give the possibility of cool effects – or, for the traditionalist, these can be disabled to keep the pure, clean glow of the Nixie filaments.



Right
At 58 cm long by 20 cm tall, the Zen clock is enormous

Objet 3d'art

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

The ‘Hello World’ of 3D printing is a little boat called 3DBenchy. Benchy models are usually made as a test to make sure that the 3D printer is calibrated properly. They’re not meant to be actually sailed in – no one would set sail in anything that’s come out of a 3D printer, would they?

No one, that is, except the hardy souls at the University of Maine, in the USA.

This boat’s hull is 7.6 m long and weighs 2.2 tons, and was printed in 72 hours in one continuous print. That was enough to earn it two Guinness World Records – it’s the world’s largest 3D-printed boat, and also the world’s largest, solid 3D-printed object of any kind.

To produce the world’s largest 3D-printed object, you need the world’s largest 3D printer. The one used by UMaine has a print volume of 30 × 6.70 × 3 metres, and uses plastic filament that contains 50% wood-fibre cellulose to achieve a strength comparable with steel.

Meet The Maker: Dalibor Farny

Vintage technology polished up to 2019 standards

Nixie tubes are fascinating things. They glow with the light of a bygone age, an obsolete technology that pulls the imagination to the 1950s and 1960s. There are plenty of second-hand units knocking about on eBay, but if you want them new, there's only one person in the world making them: Dalibor Farny, in his factory in a castle in the Czech Republic.

"A Nixie tube is a display for numerical data," he says. "If you look now at Nixie tubes, it's quite a strange way to display numbers, because we use so many types of numerical displays, like LCD displays and all this fancy stuff. It's quite alien technology for displaying numbers. But if you take it from the historical point of view, when Nixie tubes were invented, there were not so many ways to display numerical data.

"Nixie tubes were first commercially produced in the 1950s, and at this time they were one of the few ways to display digital data; all the other display types were analogue, with a moving needle. Production of Nixie tubes started because there was a sudden need for displaying digital data, as it was at roughly the same time that the transistor was invented and there was this spark of binary or digital data, but they had no good way of displaying numbers. Instead of printing them to paper, they needed something more practical.

> "Nixie tubes were first commercially produced in the 1950s, **and at this time they were one of the few ways to display digital data**"

"There are several patents from the 1930s covering the same principle, but the first commercial production started in 1954, and the first factory or first group of people who started making Nixies was from Hungary. They were two brothers, their name was Haydu, and they were soon acquired by Burroughs (which was a company at this time located in the USA, in New Jersey). After Burroughs started manufacture, the technology spread worldwide.

"At this time, Russian and Eastern European countries had their own production facilities. They didn't pay patent royalties; they just started up on their own.

END OF AN ERA

"In the 1980s the Nixie tube was cancelled in most of the factories, because there were LEDs and LCDs, but in Russia, it was still running until 1993. I'm not sure why they continued running so long with the technology, but they manufactured Nixie tubes ten years after it was stopped anywhere else. They were making tubes with no market for them, so they produced the tubes just to go into storage.

"After around 2005, there was this boom in interest in Nixie tubes, so people in Russia and Ukraine began to search through the old stock and started selling them online, in huge quantities and at prices that are significantly below the cost of production – even below the cost of manufacturing them back then in Russia.

"I'd never heard of Nixie tubes before about 2011, when I accidentally found them on the internet. →

Above
The tubes that Dalibor produces are the biggest on the market: 120 mm × 50 mm

"I was born into the digital era and had never seen anything like vacuum tubes used for displays. It was just really exciting technology. I started searching and gathering data about how they work, and the history was very exciting for me. When I learned that they were no longer produced, I was tempted to try it for myself – they're so beautiful that I had to resurrect them.

"Before this, I was a programmer. I spent seven years writing software. It was an easy life, but it wasn't fulfilling. I like to work with my hands, so I knew I didn't want to do it forever. I came across an account on Flickr, the website for sharing photos, showing high-speed photos. There was a photographer doing things with a special flash so that the photo looked like a frozen explosion. I tried to do this myself and was looking for a gas mixture for the flash. From this search, I found Nixie tubes. All the camera flash things went in a box in the cellar, and I started working on Nixie tubes instead.

WORKING IN A CASTLE

"The factory is located in a castle with 1 m thick walls. We have roughly 250 square metres of space inside. It's in a small village, and there's no budget to do anything with it – in a bigger city, it would be an art gallery or something like that. They're just happy there's a company in there paying the rent. I like it, but it's impractical on a few levels. It's humid; it's cold, there's no loading or unloading bays. But it's the closest place to my home, and it's the lowest rent around, so it was a sound business decision.

"When I started, I spent two or three years gathering information and trying to set up the highest-quality manufacturing possible – purity of materials, purity of the gas in the tubes, the best equipment, so we can produce the best Nixie tubes ever. There were problems at first, of course. The first batch of maybe around 50 Nixie tubes started to fail after around a year, so we had to take them back from customers, analyse the problem, find the solution, and prevent problems in the future.

"Now we have roughly a 4% fail rate, and we're constantly bringing that down. When you read the theory, it sounds simple, but the reality is that it's much more difficult than it first looks. We work constantly on quality inspections, on the things that we make and on the materials that we get from suppliers.

"If we were a bigger company with 20 engineers, then setting up the roles for this would be easy, but we're just three people in production. It's quite a challenge to set up the processes so that they run consistently.

> "We make everything by hand, which sounds cool, **but it's partly because we didn't have the machines to do things for us**"

"We only make one type of Nixie tube, plus a separator for use in clocks – it lights up like a colon to separate hours, minutes, and seconds. I've started working on a slightly smaller type of tube that we'll be able to offer at a lower price to the customer.

"Our customers are interested in technology – some people buy paintings for their wall; our customers buy a technical piece of art. I think they appreciate the fact that someone is keeping old technology alive and they want to support us.

"We make everything by hand, which sounds cool, but it's partly because we didn't have the machines to do things for us, in particular, the glass-work. In 2019 there are no companies making machine tools for making Nixie tubes, so we've been looking for old machine tools in archives of Nixie tube manufacturers. Most of these machines went to scrap, but they're rare anyway because only a few of them were ever sold. With the smaller tube, I've managed to find a machine to help me produce this new tube. I only found the contact to get in touch with the person who had this machine because I was already producing Nixies by hand, and the community helped me find this man who had a machine who sold it to me because he wanted to see it in operation, rather than gathering dust. Thanks to the first generation of our Nixie tubes, I'll be able to produce the second generation." ◻

Above
Working in a castle, and building 1950s technology by hand

Once upon a creation bold

Though who made it, we're never told

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**

Once upon a time, in the land of fairy tales, there was a king. And a princess. And a whole load of other characters. Wizards, witches, dragons, and talking animals lived together in a world in which the majority lived on subsistence farming. As usual, the farmers, goatherds, and the cooks all have minor parts in this story. They are there to highlight how special the main characters are; compared to the 'ordinary'.

But, unlike normal fairy tales, this one focuses on the makers. The carpenter doesn't just make a wooden puppet boy that steals the show. The cobbler makes something other than boots for cats. And the stonemasons don't rely on Medusa to make their sculptures. And, they are all paid handsomely.

It was that last bit that made you stop believing wasn't it?

Joking aside, I do like to think about the lives and careers of the makers in story tales.

Blacksmiths do get quite a few roles – from forging weapons for wars, shoes for horses, and occasionally tricking the devil. There's never any mention though of who creates the beautiful things – the candlesticks, the huge, locked, wrought iron gates that are overgrown with ivy, and keep everyone out of the forgotten castle's grounds, or the carriage lamps with the fancy twirls and finials.

The gold and jewels – of which royalty and dragons are so fond – could possibly have been mined by Snow White's seven dwarves. Silversmiths really don't get much of a mention in folklore – but someone must have made the silver bullets to kill the vampires and werewolves. And who made the vampire's clothes? I can't imagine them being tailors or seamstresses.

Joking aside, I do like to think about the lives and careers of the makers in story tales

And although everyone drinks beer in the tavern, I don't ever recall a brewery, or a discussion on the metals used to make tankards. The main creativity throughout is music – and I get the feeling that the musicians made their own instruments.

Fast forward a few thousand or so years, and science fiction isn't much different. Space travel and aliens may abound, but I can't remember reading anywhere much creativity was going on that wasn't in politics, war, or music.

It's funny how we all grow up with creativity as a baseline in our literature and cultural knowledge, but often it is bashed out of us in school, where only 'easily measured' deliverables are rewarded. And, sometimes, music.

Open-source hardware

Sharing is caring

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.

This October, people all over the world celebrated Open Source Hardware Month with meet-ups, talks, and workshops. The month kicked off with events at RAIT in Vienna (Austria) and SparkFun in Colorado (USA), followed by gatherings in Poland, Panama, Thailand, Japan, Ghana, and more!

In total, there were 40 events in 14 different countries across five continents. But, while many people in the maker community will have used some kind of open-source hardware technology – such as an Arduino – there is some confusion about what the term actually means.

> **You should also make sure the components can be purchased by others, ideally in small quantities**

Open-source hardware is hardware whose design is made publicly available under one of the many open-source licences. For electronics, this means releasing not just the schematics, but also the board layout file and the bill of materials. You should also make sure the components can be purchased by others, ideally in small quantities. This makes your designs easier to reproduce or build on.

Open-source hardware creates a space for creativity and innovation by allowing people to look into the way a thing is built. Education – at traditional institutions or through the informal sharing of knowledge that the maker movement is built on – is a natural fit for open-source hardware. The process of documenting, sharing, referencing, and building off the work of others is already encouraged in educational settings.

It's not just education though: many of the most well-known companies in the maker movement are built on open-source hardware, including Adafruit, Arduino, SparkFun, Olimex, and Prusa. Nathan Seidle, founder of SparkFun, says that for him, the advantage of open-source hardware lies in the speed of innovation that it demands. He explains that, "it has made SparkFun a better company – because we must come up with ways to innovate at a faster pace."

Now that Open Source Hardware Month is over, we're gearing up for our big event of 2020: the Open Hardware Summit! People from all over the world will be coming to New York City on March 13, to learn from each other and listen to talks from engineers, makers, educators, artists, scientists, and designers – and we want you to be part of it!

Our call for speakers is now live at **2020.oshwa.org** so, if you've been working with open-source hardware, and have some good knowledge to share, cool projects to show off, or a great story to tell, we would love to hear from you. □

Letters

ATTENTION ALL MAKERS!

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

PRINTING

I filled in your survey on 3D printing, and realised that I've never designed anything for it yet. I bought a Prusa i3 and downloaded the free version of Fusion 360 with the best will in the world. But all I ever seem to do is print widgets off Thingiverse. Does anyone else have this problem? I feel like I should be creating things, but I'm not.

Philip
Kingswood

Ben says: That doesn't sound like a problem: if you're using the technology for its stated purpose, making useful things that you wouldn't normally have access to, then the 3D printer is doing its job. Plus, Fusion 360 is hard, and working with established designs will help you get your head around it when you do start to learn that software. Until then, turn to p106 for tips on perfect prints.

BREWING

Cheers for the beers! I've got some mead on the go now for Christmas. Quality control will, needless to say, be rigorous. But is it just me, or is there something wrong about making cider out of shop-bought apple juice?

Paul
Ely

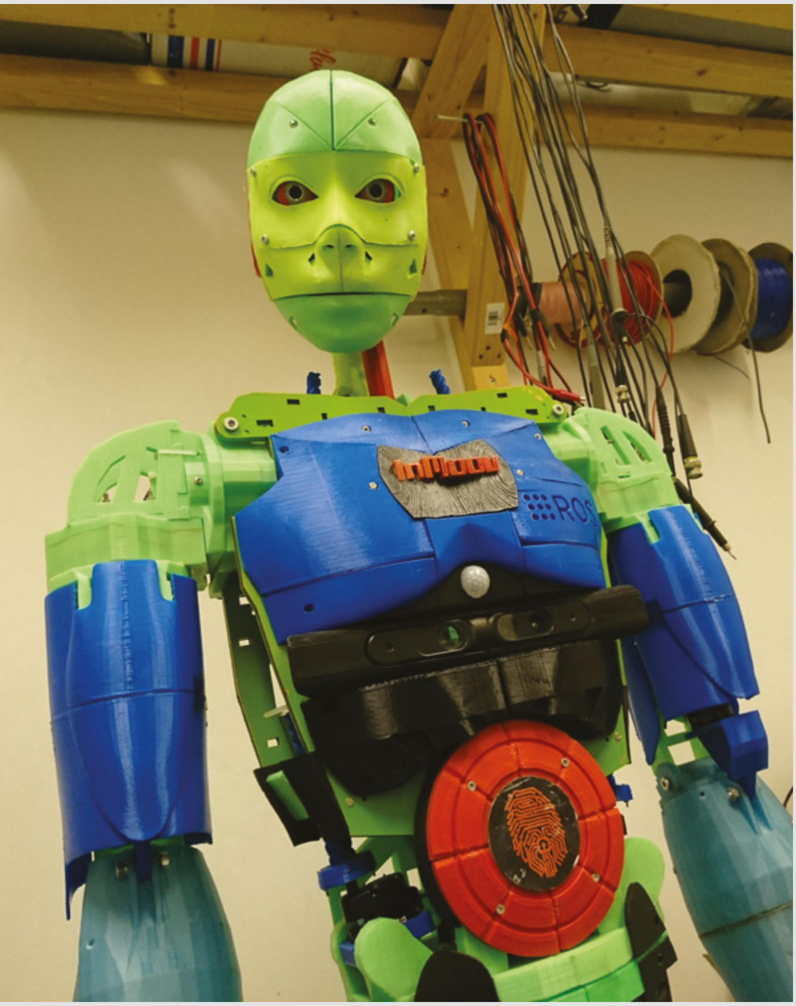
Ben says: Purists may sniff, but there's no legal protection on cider. A solution of sugar, apple flavouring, and industrial alcohol is just as much cider as a drink made from hand-pressed Herefordshire apples. When you make cider from apple juice, all you've done is outsourced the messier stages to skip right to the fun parts.

ROBOTS

A simple request: more robots, please. Not smart machines that can tenuously be called robots: actual robots, like Kryten from *Red Dwarf* or C3-PO from *Star Wars*. That is all.

Keith
Glasgow

Ben says: **The thing about robotics is it's hard to do anything resembling a human. You're really best off building one robot to perform one task and changing them together, rather than building one humanoid robot that does it all. That said, maybe we should work on a robot butler in time for Christmas 2020.**



WELL-BEING

Does anybody else around here just like making a mess? When I come in from the garage, my wife asks me what I've been making, and the answer is usually just a big pile of sawdust, but it feels great. Is there an equivalent for electronics? Is it just as therapeutic to solder together a load of resistors for no reason and pretend you've done something useful?

John
Seville

Ben says: **I don't know about electronics, but the brazed flower I made out of old coins for this issue is pretty useless, and a little on the er, lumpy side. But it did feel amazing to do, so I'm going to say yes. Working with your hands is good for the soul.**

CROWDFUNDING NOW

DepthAI

Offload your vision processing

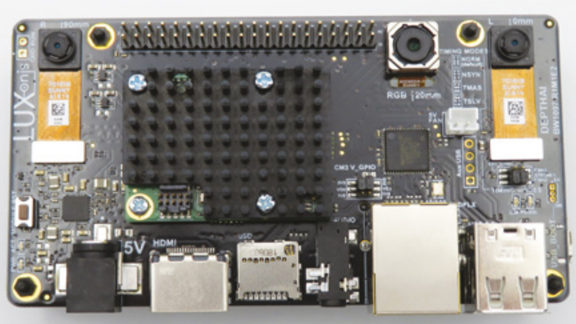
From $99 | **hsmag.cc/VDxhLQ** | **Delivery:** Feb 2020

The basic idea behind stereo vision is that cameras (or eyes) that are positioned apart from each other will see slightly different things. The more 'different' an object looks to the two eyes, the closer it is. By combining these two images, we can see how far away something is. That all sounds very easy, but in practice, there are a number of problems to overcome – unless the two cameras are exactly in sync, and movement can have a larger effect than the distance, working out exactly what is an 'object' requires some clever tricks, and even more so to work out what a particular object is.

DepthAI bundles all this into one hardware platform with a Python interface. Load up your object classifier (trained in OpenVINO), and you'll get a steady stream of data telling you what's currently in the frame and in what position (with X, Y, and Z values). As with many AI-based systems, running a model is much easier than creating a model, so the utility of a system like DepthAI depends on whether there are existing models that fit your needs. There's a range of models at **hsmag.cc/xw8Cfe** that should work with this hardware, but if you want to do something different, you'll need to train your own.

The hardware comes as a Raspberry Pi HAT, an all-in-one board with a slot for a Raspberry Pi Computer Module or a USB attachment that can work with a PC.

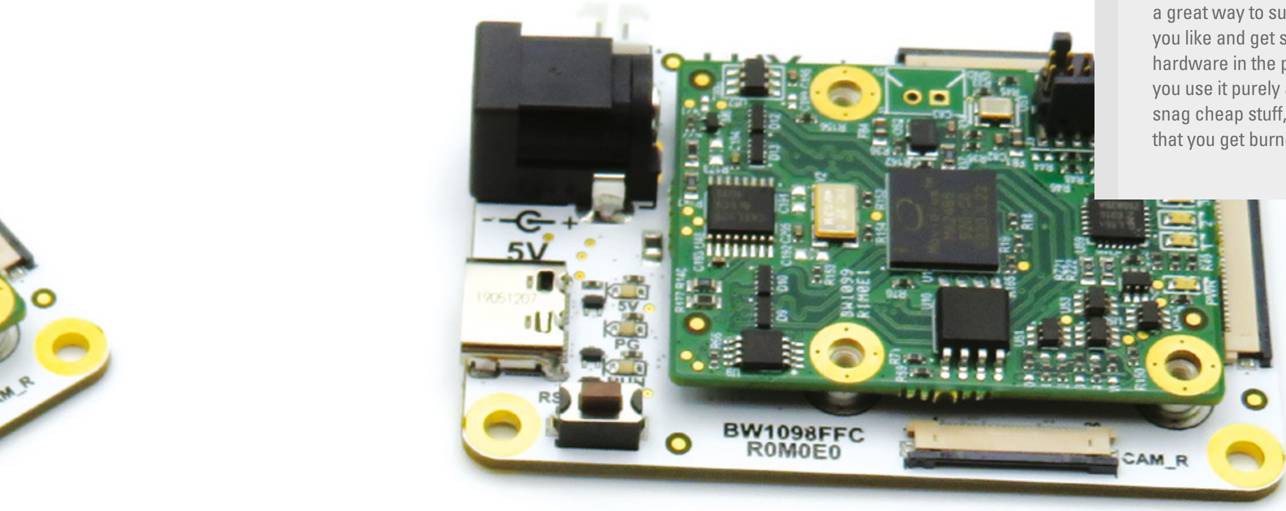
Luxonis claims that the hardware will run models at 25fps. We've not verified this, but if true (or even if the results are close to this), that adds a lot of visual AI power to your Raspberry Pi. Since all the processing is done in the DepthAI module, there's very little load on the Raspberry Pi, so you can then do processing on the position data.

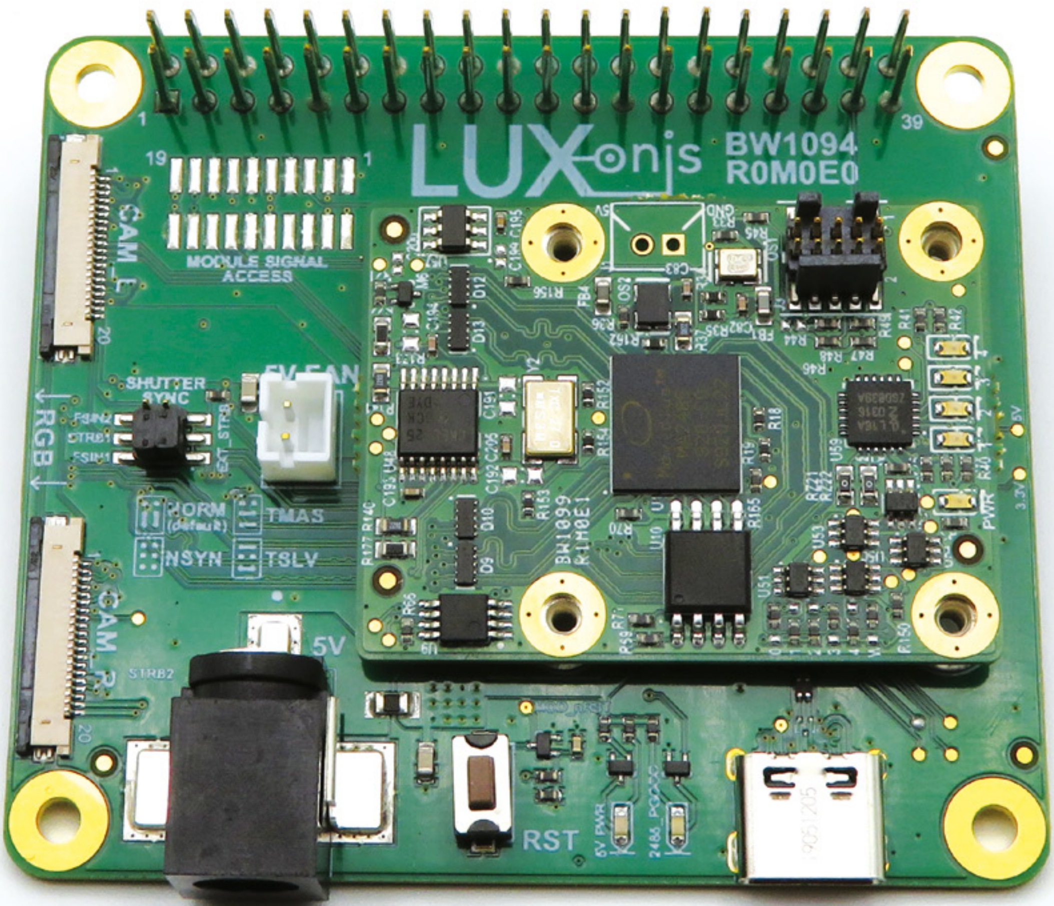


Above The Compute Module kit – just add power and a monitor, and you'll be running depth processing

BUYER BEWARE

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





Left Add your vision processing to a Raspberry Pi, or any PC, with a USB port

Space of the month: Hackerspace.gr

Hackerspace.gr

- Hackerspace.gr
- Hackerspacegr
- @Hackerspacegr
- Hsgr

Set in a basement on a residential street, around 20 minutes ride on the metro train from Athens city centre, is Hackerspace.gr (HSGR). It's a vibrant and cheerful place that is welcoming from the outset.

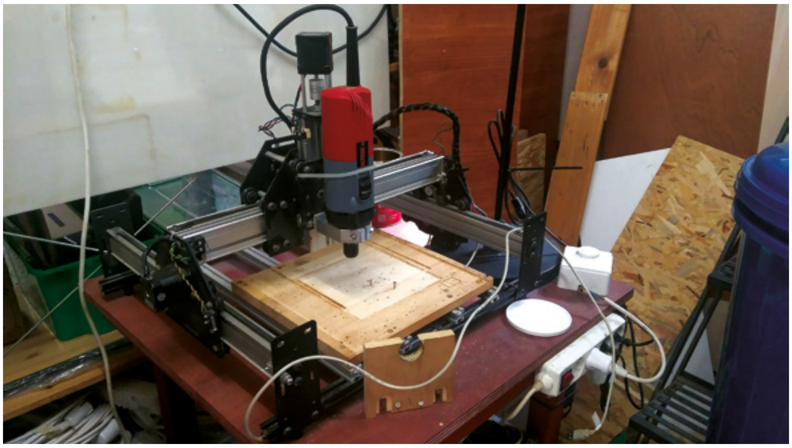
Running since 2011, HSGR is open every day and evening and is free to use, with some members opting to pay a small subscription to keep the place afloat. It's extremely well equipped, and some of that is a testament to the astonishing projects that have come out of this space. SatNOGS and the Libre Space Foundation were born here, but the list of projects is longer: cryptoparties, high-altitude ballooning, food hacking, working on OpenROV projects, and more can be found on the events calendar.

The first part of the space is the computer lab area with lots of desks and work area. It can be reconfigured as an event space and is suitable for hosting workshops – for example, the Athens NASA Space Apps hackathon is held here. Decent WiFi, projector and screen, and a fridge full of cold drinks make this a useful space, with the DIY RetroPie arcade machine providing some entertainment. Due to space constraints/ventilation, the A3 laser cutter is also in this section.

Moving to the central section, we find a long, wide corridor with a small kitchen on one side and a massive, long workbench on the other. It has plenty of workspace and a good collection of hand and power tools. Projects that have been developed in-house are to be seen, with a DIY vacuum chamber and an experimental satellite deployment system on the bench. A good-sized benchtop lathe stands next to a larger benchtop manual milling machine and the associated tooling for them is either new, or there is a great collection of second-hand, quality Russian tools sourced from local flea markets and traders.

In the furthest part of the space, we turn a corner into a well-equipped electronics lab – multiple, quite costly pieces of equipment catch our eye, such as the high-end signal generator and the bank of differing →

Above The middle section of the space, always busy and in use

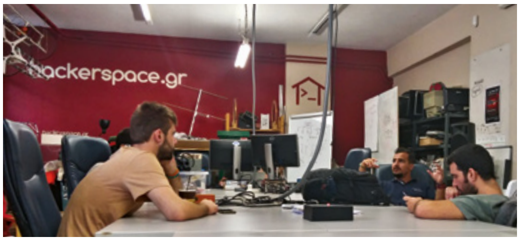


Rigol scopes. A drone project hangs from the ceiling, and a collection of SatNOGS project rotators are stacked in a corner. We featured the SatNOGS project in issue 18, but as a reminder, it's the open-source decentralised network of DIY satellite ground stations that span the globe, and the project that won the 2014 Hackaday Prize. That year's prize was substantial and enabled the formation of the Libre Space Foundation, which in turn led to projects such as UPSat, the open-source CubeSat that was deployed to low Earth orbit from the International Space Station.

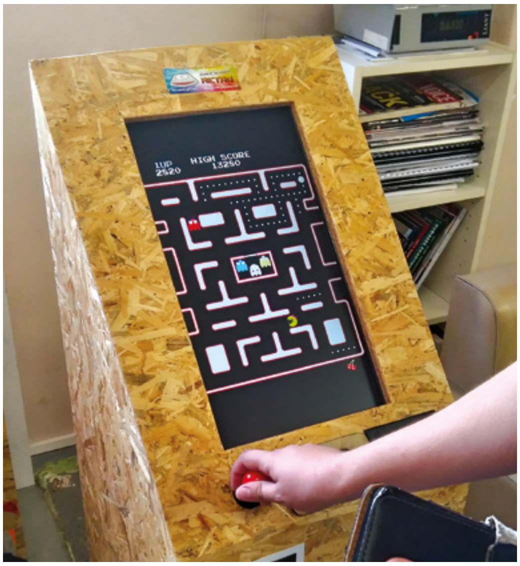
We finish the tour with a corner that has a few 3D printers and a modified Shapeoko 2 CNC machine. It's really well-equipped as a space and has such a wealth of knowledge and skills shared in its members. If you are in Athens, we recommend you go and check out this friendly and well-established space. □

CONTACT US

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



Above
The main computer lab which doubles as an event space



Above The universally well-hacked Furby, hung on the noticeboard

Left Some very high scores on this DIY RetroPie machine, in particular on Tetris

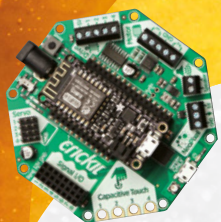
Above A great selection of hand tools, sewing machines, and an engineering model of UPSat satellite, somehow typifies the range of projects here

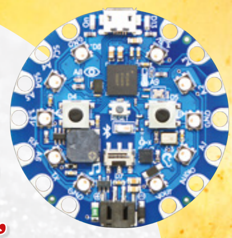
HackSpace
TECHNOLOGY IN YOUR HANDS

LENS

HACK | MAKE | BUILD | CREATE

Uncover the technology that's powering the future





PG 34

MAKER CHRISTMAS PRESENTS

Rejoice! It's the time of year for gifts, mince pies, and James Bond on TV

PG 52

HOW I MADE: AN ARTIFICIAL CANDLE

Cold fire, you've got everything but cold fire. So why not make some?

PG 58

IN THE WORKSHOP: PRIMITIVE ART

Free-form sculptural circuits, plus brazing flowers from coins and a length of chain

PG 62

INTERVIEW: SAM UNDERWOOD

Making music, sound sculptures, and the importance of experimentation

PG 70

IMPROVISER'S TOOLKIT: COTTON BUDS

Don't put them in your ears – make something with them instead!

PG 74

BELA AND BEAGLEBONE

Ingenious instruments with this low-latency single-board computer

MAKER CHRISTMAS PRESENTS

The best tools, toys, and trinkets for your hacker Christmas list

It's that time of year when we're all writing to Santa (OK, heavily hinting to partners, parents, and children) what we'd like to find under the Christmas tree.

The options for makers are in a state of flux at the moment. Take electronics, for example. In bricks and mortar terms, things aren't looking great. With Maplin gone, there are no electronics stores on the British high street (unless you're in Cambridge, where you should take a look at the Raspberry Pi Store), and the situation in other countries isn't looking much better.

However, head to the internet and you see a different picture. The last few years have seen a renaissance of hobbyist electronics products – what's particularly encouraging is seeing a flourishing market for small enterprises through sites such as Tindie and Crowd Supply, as well as the more established names. It's not just electronics – online craft shops allow access to a far wider range of materials and equipment than ever graced our high streets, and tool stores will deliver just about anything to your door in just a few days. In other words, if you need it for making, you can get it online.

The problem with this online world is that there's no high street to idly wander around to find those things you need-but-didn't-know-you-needed. Well, that's what we're here for. We've scoured the makerverse for the finest tools, toys, and trinkets. Feel free to circle items and leave the magazine open in prominent places around the house, to make sure that people get the hint. →

PROGRAMMABLE BOARDS

The heart and soul of many electronics projects

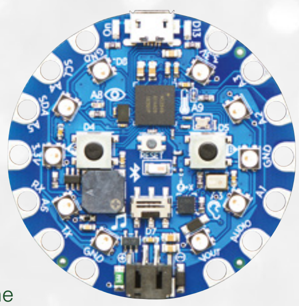
We're currently living in a golden age of programmable boards. Over the last decade, there's been an explosion in the range and quality of embeddable boards, both microcontroller-based, and Linux-based. These have made it easy to add interactivity to our projects, whether that's allowing an interaction with a user, connecting a device to the internet, giving some AI capabilities or any of a wide range of different uses.

There are many trade-offs in the design of these programmable boards – size, performance, power consumption, ease of use, onboard features, expandability, and more; all have to be considered – so there will never be a perfect microcontroller. We've picked our five favourite boards of the past few years. Each excels in different areas, and we've had great fun with all of them. You just need to decide which is right for you.

Playground Bluefruit

adafruit.com | $24.95

The Circuit Playground Express is a fantastic board. We like it so much that we made it our subscriber gift for 12-month subscribers.



The combination of a load of sensors, ten NeoPixels, and a form factor suitable for crocodile clips and wearables makes a great board for testing out ideas quickly and easily. It's still a great board for getting started, but this month we've been playing with the Circuit Playground Bluefruit, and it brings everything we liked on the Circuit Playground Express, but with the addition of an easy to use smartphone app, that lets you add remote control to your projects. It's a fantastically easy way to link your phone to your projects.

Teensy 4.0

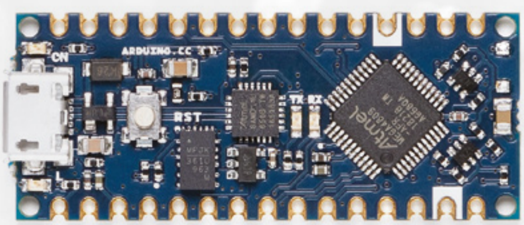
pjrc.com | $19.99

We first looked at this board in issue 20, and we loved it. It's startlingly powerful and startlingly small. Perhaps our favourite aspect of this board, though, is the Audio library. This is a powerful synthesis and effects library that runs on Teensy boards (and a few others). The Teensy 4.0 is, hands-down, the best microcontroller board around for hobbyist music. Of course, the fast M7 CPU will find uses in many different areas. If you're feeling constrained by the processing power of microcontrollers, this is the board for you.

Arduino Nano Every

adafruit.com | €8.00

This tiny board from Arduino has some great things going for it. It's 5V, so it's easy to interface with hardware running at this voltage (such as NeoPixels), it's powerful, at least compared to other 5V microcontrollers, it's tiny enough to fit into tight spaces, and it's cheap at only eight euros. Yes, there are cheaper boards around, but this is solidly built, and comes with support from Arduino.



Raspberry Pi 4

raspberrypi.org | $35

Unlike the other boards we've looked at here, this isn't a microcontroller, it's a full PC, and runs the Linux operating system. Plug in a monitor and keyboard, and you can use it as a desktop (HackSpace magazine editor Ben Everard does just this). However, without these, you can use it as an embeddable computer. It's got far more processing power than even the most powerful microcontrollers, and also fantastic software support including databases, web servers, and image processing tools. If you want to process or store data on your board, this could be the one for you.

ALSO CONSIDER

BARE CONDUCTIVE TOUCH BOARD

bareconductive.com

While many boards have touch-sensitive pins, this one combines large pads that are easy to crocodile clip to, an SD card reader, and an audio amplifier. This combination makes it great for triggering sound effects from touch events.

ALSO CONSIDER

TINY PICO

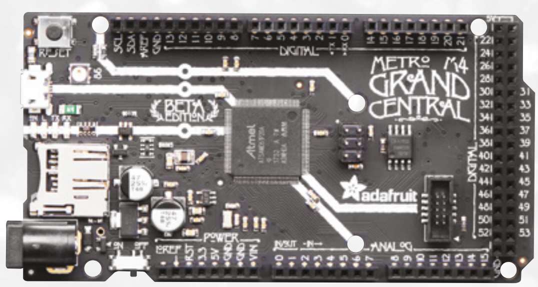
tinypico.com

The ESP32 board with everything. Well, not quite everything, but it does have a 700 mA regulator, 4MB of PSRAM, and battery management on top of all the usual goodies we've come to expect from ESP32 boards.

Grand Central

adafruit.com | $37.50

We'll be honest; this is the most in-demand microcontroller at HackSpace magazine towers. It's got loads of processing power, loads of storage space, loads of IO, and you can program it in either Arduino or CircuitPython. Yes, it's overkill for most projects, but when you're prototyping or just scoping something out, it's a great board to reach for. Once you've narrowed down your requirements, you can always scale back to something a little smaller. →



MODULES, ADD-ONS, SHIELDS, AND HATS

The best ways to level-up your hardware

If we have made better projects, it is by standing on the shoulders of giants, and those giants in question are the people who make add-on boards. Yes, you can take your microcontroller and expand it with circuitry – and if you're interested in electronics, this can be a fun option. However it's much quicker and easier to build your projects out of known, tested modules, especially if these modules come with code libraries that you can lean on to do the hard work. There are more of these modules than we could possibly count, and many of them serve a particular niche well. Here, we're looking at some great modules that it's useful to have in your maker kit as they'll come in useful time and again.

ALSO CONSIDER

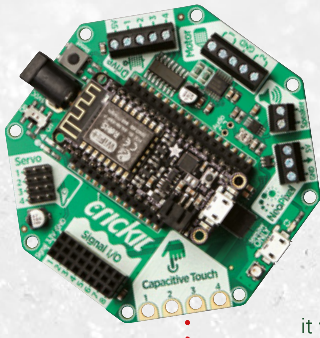
TEENSY AUDIO ADAPTOR

pjrc.com

Works with Teensy boards (with correct adaptor). Includes an SGTL5000 which converts the digital signals to analogue waveforms that we can listen to.

CRICKIT

adafruit.com | $29.95



Adafruit's CRICKIT is a Swiss Army knife for maker projects. It's got NeoPixel outputs, sound output, motor drivers, servo connectors, capacitive touch input, and high-current outputs. You probably won't need all this for any one project, but it probably has all the bits you need for many of your projects, so it's one accessory that you can use over and over again. What's even better is that it comes in flavours that can attach to Circuit Playground Expresses, Raspberry Pis, micro:bits, and any Feather-compatible board, so you can use it with whatever controller board you like.

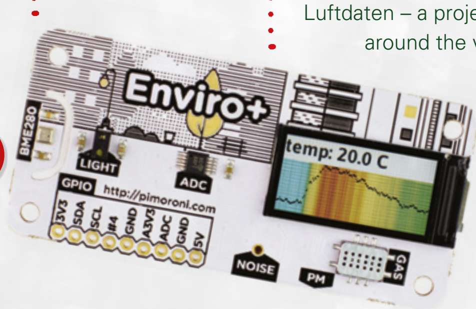
Enviro+

pimoroni.com | £45

The Enviro+ slots on top of your Raspberry Pi to enable it to sense a range of different things including temperature, humidity, light, volatile gases, and sound. There are also connectors for a particulate matter sensor (sold separately). You get output with the 0.96-inch colour LCD. If you need more, there's an extra analogue in and an I²C connector on the board.

It was developed in partnership with the University of Sheffield for citizen science, and the Python library comes with support for uploading your data to Luftdaten – a project for mapping environmental data around the world.

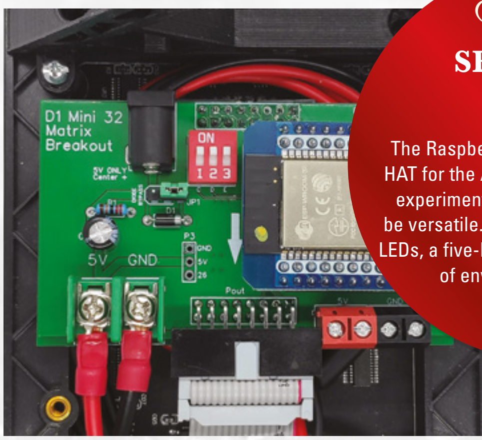
Whether you want to contribute to the global understanding of pollution, or just keep tabs on the environment in your workshop, the Enviro+ gives your Raspberry Pi the hardware it needs to keep you updated with the information you need.



ESP32 Matrix Shield

tindie.com | $14

RGB LED matrixes are widely available and cheap, but can be a bit hard to control. Brian Lough has created expansion boards for the Mini 32 (ESP32), D1 Mini, and Tiny Pico to let them easily connect and drive these displays. You use these displays without a driver board, but it's easier and neater with one (there's a lot of wires to connect!) – just plug the matrix into the socket, and plug the board into the headers and you're ready to go. These boards support daisy-chaining (the maximum size depends on the power of your microcontroller), so you can build up larger displays. Left bare, these displays give a pixelated effect, but you can add a diffuser or templates over the top to give them a unique look.



ALSO CONSIDER

SENSE HAT

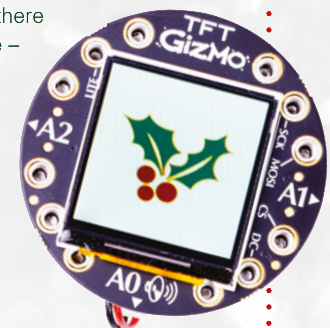
raspberrypi.org

The Raspberry Pi team developed this HAT for the Astro Pi mission, to perform experiments in space, so they had to be versatile. There's an 8×8 grid of RGB LEDs, a five-button joystick, and an array of environmental sensors.

TFT Gizmo

adafruit.com | $19.95

You might look at the shape of the Circuit Playground Express and think that there's no way you can get an add-on board on it, but you'd be wrong. Rather than pin headers that most boards use, Gizmos use bolts and standoffs to hold expansion boards firmly in place, and these same bolts also provide an electrical connection. At the moment, there are only two Gizmos available – a proto board add-on and a TFT add-on (which graces this issue's cover). The circular shape of the Circuit Playground means that Adafruit have been able to fit a 1.54-inch (39 mm) 240×240 pixel display. This is plenty of space for a bit of graphical output, whether functional or purely aesthetic.



Pololu motor drivers

pololu.com | $3.45

If you want to drive a small DC motor, then you just need something that can switch an amp or two. However, if you're looking to go a bit more powerful, you need to go a bit more specialised. If you're pushing the limits of hobbyist robotics, you might find yourself needing to switch tens of volts at tens of amps, and that will transform simple motor drivers into ash pretty quickly. If you need a specialist motor driver, Pololu is a great place to go. They make drivers for a wide range of power profiles, and have a good guide to help you select the right driver for your motor. Most drivers are in modules that are independent of the controller board you're using.

If you want to move a bot fast (or move a heavy bot), this is the place to go to pick your board. →

KITS

Everything you need for a beautiful build

Kits come in many forms, and they let you get stuck into the nitty-gritty of something without getting bogged down in complex design first. When you're getting started in a new area, they let you get on and actually make something without having to fully understand all the detail. When you've got more experience, they give you a standard set you can work with and build upon. This Christmas, why not ask Santa for a kit in an area you're currently unfamiliar with? It'll allow you to dip your toe into a new range of making, and might help you pick up a few new skills along the way.

Picade

pimoroni.com | from £150

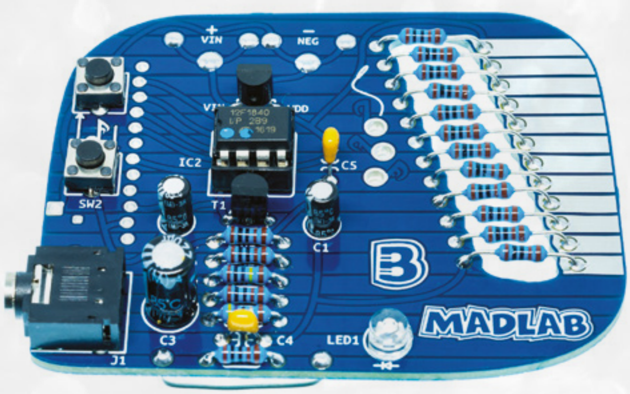
For a certain aged reader, the arcade cabinet is the symbol of all things gaming. For this writer, it's memories of Golden Axe at the local leisure centre after swimming lessons, then later, Super Bomberman at the sports hall opposite the sixth-form centre. A full-sized arcade cabinet is a great thing to own, but only if you've got the space. For those of us in more modest-sized houses, Pimoroni's Picade brings the form factor of arcades to the tabletop.

A Raspberry Pi provides the horsepower, so you can play a huge range of games. It adds to this a sturdy joystick and arcade button interface, and an 8- or 10-inch display. All this is housed in a solid frame that's small enough to tuck away at the end of a gaming session.

Boldport kits

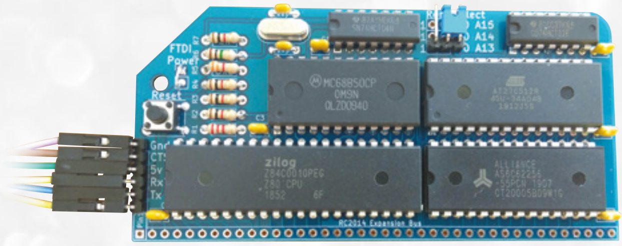
pimoroni.com | $14.10

The Boldport Club once sent out monthly electronics kits to subscribers, but these kits were unlike any we've come across before. Each one was part electronics, part art, part puzzle. Some were a challenge to put together (such as the legendary cordwood kits), some experimented with 3D PCB structures (such as the Pineapple and the Monarch), some introduced interesting components or circuits. The club, alas, is no more, but the kits live on and are sold by Pimoroni. Some are easy, some are hard, some are useful, but all are great fun to play with.



RC2014 Z80 computer

tindie.com | $77



Have you ever wanted to build your own computer? No, not just plugging the CPU into the motherboard, but getting out your soldering iron and actually building it? Great! This is the kit for you. It might not be the most modern computer, in fact, it's based on the Z80 processor popular in the 1980s, but it was popular then for a reason. It's powerful enough to be useful, but simple enough to be understood. With a bit of effort, you should be able to understand the complete operation of your RC2014, and if you can fully understand it, you can design and build your own extensions. This can be a retro computer to satisfy your nostalgic itches, it can be an educational tool to help you understand how computers work, or it can be a blueprint for a customised computer built for your needs.

Kintsugi kit

humade.nl | from £24

Stuff breaks – that's a fact of life – but it doesn't have to stay broken. A surprising amount of stuff can be put back together to be as good as new. However, sometimes, no matter how much you try, a broken thing never looks quite as good as it did before it broke. Ceramic, for example, will often always show cracks, and if little bits come out, these can be nigh on impossible to get completely back together. Why should we care though? If something can be restored to its full function, does it matter if it looks broken? These scars are a sign that the object's been used, and that's a good thing! Kintsugi is the Japanese word for using gold to repair an item. In this way, the cracks aren't hidden, but celebrated. In its traditional form, it's hard to learn this art, but with modern materials, we can find easier methods to get similar results. The Kintsugi repair kit by Humade includes epoxy glue, epoxy putty, and gold powder, so you can piece your ceramic back together into something more beautiful.

Three Fives

Evilmadscientist.com | £35

The 555 is an unassuming chip. To many people, it's a thing that can make LEDs blink, and it can, but it's the chip's versatility that makes it the most widely used IC in history. If an application requires any form of timing or delay, there's a pretty good chance that it can be done with a 555. Despite its ability to do seemingly anything, it's actually a fairly simple chip. The Three Fives Timer kit, from Evil Mad Scientist, is a kit for you to build your own version of this chip out of discrete components. The final product is a fully working 555 that you can use in your own circuits, though it is a touch larger than the original integrated circuit.

This is a fun thing to play with in its own right, but it's also a useful learning tool to help you think about circuits in terms of discrete components rather than chips. You don't need to ditch the ICs, but it can be helpful to understand how to get by without them sometimes. →

DIRECT FROM CHINA

Our favourite finds on direct-from-China websites

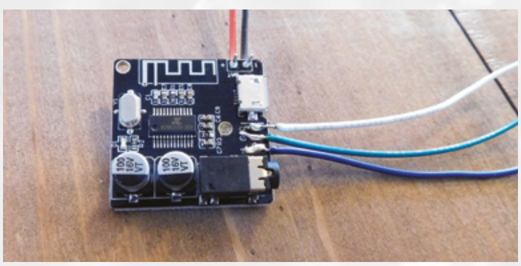
Since issue 1 we've been exploring the weird and wonderful world of direct-from-China websites. Here you can buy almost anything at rock-bottom prices. The problem with 'almost anything' is that it includes the bad as well as the good, and it can be hard to separate the two. We've been delving through the more unusual side of these websites to see what we can find that's useful for makers, and testing out if they really work.

Bear in mind with any of these, they may or may not have been safety tested, and don't generally come with much product support, so it's up to you to make sure you understand the risks of working with them.

Third hand

Holding bits together while you solder them can be a tricky task, but thankfully, third hands are here to help. There's a wide range of different options to choose from, and on sites like AliExpress, you can select just the bits you want. We use lead-free solder here, so a fan to keep the fumes away was an important feature for us, as are plenty of hands. However, that's just us. Pick the bits you need and build up your personal choice of third hands to make soldering as easy as possible.

Bluetooth audio receiver



We've had a love-hate relationship with Bluetooth audio receivers from direct-from-China websites. The ones we've bought that just contain the Bluetooth element have worked well, while the one with a built-in amp was awful. We've since tested out another unit with a built-in amplifier, and it worked well. This is definitely an area where it pays to be a bit careful. However, for just a few pounds, you can turn old hi-fi equipment into a Bluetooth speaker. HackSpace magazine editor Ben Everard has had a 1940s radio running as a speaker in his kitchen for several years with a setup like this, and it's worked really well.

RC boat electronics

Making wheeled robots is a right of passage for many makers. There are loads of ways of building them – line followers are a classic, but you can also add a bit more intelligence. Flying drones are also popular these days, but what about machines that float? We found a kit for making radio-controlled boats. There's not a lot to it, just two motors with propellers attached, and a mounting rig to help you attach it to your craft. The controller just switches the motors between forwards, backwards, and off to let you move and steer. You can use this kit in many ways. The simplest is to build a craft for it to be mounted on (we used an ice cream tub), and you've got yourself a radio-controlled boat. If you want to go further, you can easily run this off a microcontroller with a usual motor driver to make a smart boat.

3D pen

Take the extruder of a 3D printer and mount it in a hand-held enclosure and you've got a 3D pen. Press a button and out squirts hot plastic that you can lay down in any shape or pattern you like. While you can use this like a 3D printer and build up your projects layer-by-layer, unless you've got the patience of a robot, you'll probably not find this particularly rewarding. Instead, you can trace out sections of your build, and then stick these together to make your final object. We also found it useful for filling gaps and building small bits free-hand.

Tesla coil speaker

Tesla coils are a way of creating huge amounts of electricity. There is, by and large, no good reason to have huge numbers of volts (many thousands) in your workshop, but they do create pretty sparks. These sparks heat the air up very quickly, which causes the air to vibrate, and vibrating air is just a fancy word for sound. The kit we tested takes an audio jack input and creates sparks at the frequency and volume of the sound coming in, so you hear the music in the crackle of the lightning.

The sparks are fairly small, and the music is bad quality, but it is a great demonstration of science … or at least that's the excuse we used to justify having it in the workshop. →

BITS AND BOBS

The things that help your projects come together

The little things that aren't specific to a particular build, but are useful to have in your workshop for that inevitable moment when you'll need them. Perfect for stocking your very own 'just-in-case' box to be pulled out when a make needs a little extra push to get it to work properly. Some might say 'bodge', but we prefer the term 'informal engineering'.

Sugru

Sugru is a mouldable putty that hardens into something with the texture of firm rubber. It comes in little sachets that are the perfect size for many small jobs, and in a variety of colours so you can either blend in or stand out. They're great for small repair jobs, but can also be useful when making whenever you need to make a small 'thing'. A little stopper that needs to be just the right size? Some feet for a project to make it stand evenly on the desk? A little filler for something that wasn't quite the right size? A bracket for something with an awkward shape? This little packet will do the job.

ALSO CONSIDER

PRINTER FILAMENT

You know you always need it! You could put some unusual filament on your Christmas list – we've always been fans of wood-textured filament, but there are some great-looking other options too.

Brass rods

We first got some brass rods into the HackSpace lab for working on circuit sculptures – and they're great for that – but we also find ourselves reaching for them time and again for little things. In the portable Raspberry Pi desktop from issue 24, we used loops of this rod to route wires tidily. HackSpace magazine Editor, Ben, built a soldering iron stand with this rod when he misplaced his previous stand. This rod can be easily bent with pliers, but is stiff enough to retain its shape when under moderate load. You can solder bits together with a normal soldering iron if you need to build a larger structure.

Superglue and baking powder

OK, you might get a few odd looks putting this on your Christmas list, but it's a great combination for repairing things, or even building up small fixtures. The basic technique is that you pile a small amount of baking powder in an area that you want to be solid, then drop a little superglue on it, and repeat until you've filled all the space you want. The resulting material is fairly strong and can be filed into shape with hand tools. If you've got a gap that needs filling, or a crack that needs reinforcing, these are the materials you need.

T-Rex tape

Duct tape is an essential part of the maker's toolbox. It sticks stuff and stays stuck (as opposed to gaffer tape which is designed to be removable). This silver-coloured tape has become synonymous with the word 'bodge', but that's a little unfair to duct tape, as bodges can be stronger and tougher than the original thing that's been bodged. However, not all duct tape is equal. T-Rex tape has an adhesive that's more aggressive than most. We keep a roll of it in the HackSpace lab where we find it useful more times than we'd like to admit.

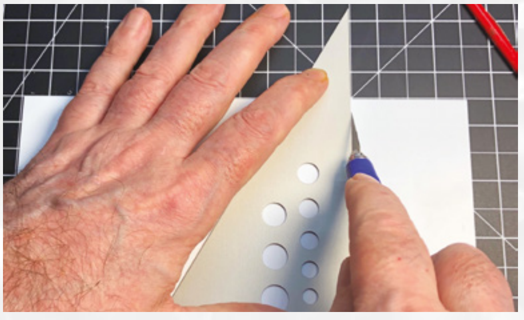
ALSO CONSIDER

SOLDER

Not all solder is equal. We've been using SparkFun's 'Special Blend' lead-free solder in our lab for a while now and it's great – it flows well and is easy to work with. Those of you of an environmental bent may like Stannol's Fairlotet recycled solder.

Styrene sheet

This staple of the model-building community is easy to work. Using just a craft knife and glue, you can build a huge range of objects quickly. If you need an enclosure to fit just the right shape, then it's a great option. The final piece may not be as structurally strong as some other construction methods, but they're quick and easy to make. Adam Savage gives a great introduction to building with this technique in a one-day-build video at **hsmag.cc/hUY6AY**.



THE GIFT OF KNOWLEDGE

Learn a new skill or experience a new style of making

There's only so much physical stuff one maker can have, so sometimes you need mental stuff in the form of knowledge. There are loads of reasons to learn something – sometimes it's to expand your skills in an area you're interested in pursuing, and other times it's for the pure pleasure of trying something new. These are more local than most of the things we've looked at, but you should find options in your area for all of these courses, and these typically include access to all the equipment you need, so it can be a great way of trying out a skill, craft, or technique without having to invest in costly hardware until you know it's something that you'd like to consider.

Blacksmithing

There are blacksmiths around the country plying their craft and teaching people how to get started. At its heart, forging steel is fairly simple – heat it until it's hot, then whack it with a hammer. However, that simplicity hides many nuances about the way the steel moves when it's hit, and how the heat affects the structure of the metal. Like so many skills, it takes a lifetime to master, but in a day's course, you'll learn an appreciation for the craft, and probably have a trinket or two to take home to show off your control over all things ferrous.

Fabric work

There are many ways of working with and creating fabric: sewing, dressmaking, tailoring, knitting, and crocheting, to name but a few. Some are very practical, while others are more about the artistic side of things, and you'll find courses for many of them in folk houses and sewing centres around the country. Getting started in any of these areas is fairly straightforward (though – like with many skills – can take a long time to master), so as long as you set realistic expectations, there's no reason you can't be wearing clothes of your own making early in the new year.

Neon sign-making

Neon signs are basically glass tubes bent into shape and filled with gas (not always neon), and a few other chemicals which affect the colour. While making a complete lighting system is an art, a beginner can have a go at forming the tubes into shape, and there are various workshops around the country that will guide you through the process. Within a day, you should have something that you can take home to light up your living room, but budget more time if you want to perfect an idea or have a complex project in mind.

Woodworking

Woodworking is a very big subject, so it's important to understand what you want to learn before looking for a course. It's common to find courses that will take you through using hand tools and creating particular joints. Others may introduce specific machines (such as wood-turning on lathes), while others may look at more specialised techniques such as green woodworking. Since the tools for woodworking are common, woodworking courses are often more skill-based than experience-based – few people going on a blacksmithing course will take the plunge to get a forge, while many people on a woodworking course will continue with the craft. As such, it's common for them to run over longer periods, and often over a series of evenings.

ALSO CONSIDER

METALWORK

Does your local technical college run evening courses? Why not sign up for a class on welding or other metalwork?

Glass-blowing

Like metal, glass also falls into the category of materials that can be worked by heating it. It's a bit more complex to get started with than working steel, but with a little guidance, a beginner should be able to progress far enough to have something to take home at the end of the day (or probably not actually take home, as it may need to cool down overnight before being ready the next day). Features editor Andrew Gregory is currently proudly displaying the bauble he blew with Hen Ogledd Glass. Bump into his Christmas tree at your peril. →

BOOKS

Bits of knowledge bound up in cellulose

We live in a world of infinite knowledge at the tips of our fingers, but there's still something special about paper. It's calm, tactile, pleasant to use, and easy to refer back to. Despite the cornucopia of knowledge on the internet, there's still nothing quite like a good book. Fortunately, there are plenty of good books on the subject of making, and here's our pick of the best ones we've read over the past few years. They're not all new, but they are all worthy of your time and attention. Grab a cup of tea, and settle down with one of these.

The Art of Electronics

For many of us, electronics is a digital thing. Our GPIO pins go on and off, and our I²C and SPI busses transmit precise instructions to the devices attached, but the electronics engineers out there know that this is an illusion. Electronics are analogue. There is no on or off, just differing voltages that have to be manipulated with resistors, capacitors, transistors, and other discrete components. If you're the sort of maker who has always wondered what's going on inside the HATs and shields you plug into your microcontroller, this is the book to help you understand the messy analogue side of the electron.

Every Tool's a Hammer

Adam Savage – 50% of the original MythBusters team – is an icon in the makerverse. Although MythBusters was ostensibly about finding out if something was true or false, the majority of the show consisted of building the devices to test this. *Every Tool's A Hammer* is part memoir and part how-to-be-a-maker, but it's 100% inspiration. If you're feeling a bit creatively drained, this book will pep you back into life and get you making again.

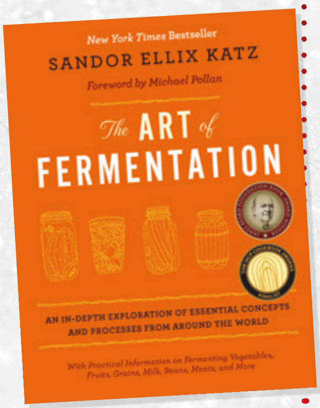
ALSO CONSIDER

GET STARTED WITH ARDUINO

We've taken the best bits of Arduino programming from the first two years of HackSpace magazine, and compiled them into our ultimate guide to Arduino. If you're new to HackSpace magazine and the Arduino-compatible microcontrollers, this is the place to start.

The Art of Fermentation

Fermentation – where bacteria and fungi transform the flavour, texture, and chemical make-up of food – is an ancient form of making. It's probably most commonly thought of as a way of making alcohol, but this is only a tiny part of what's possible. In *The Art Of Fermentation*, Sandor Katz goes through all the different areas of fermentation, and looks at traditions from around the world. Many of them are easy to recreate at home, and produce flavours unlike anything available in commercial products. It's culinary making at its finest!



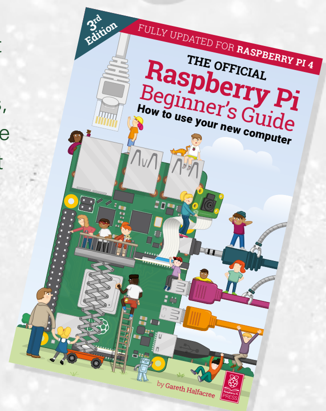
ALSO CONSIDER

RASPBERRY PI PROJECTS BOOK

Take a look at the best projects from *The MagPi* – you'll find oodles of inspiration, and hopefully learn a trick or two about how to use this tiny computer.

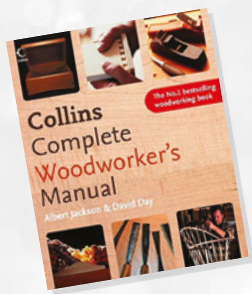
Raspberry Pi Beginner's guide

The Raspberry Pi is the most powerful of the common maker computing platforms, and Gareth Halfacree is here to help you get the best out of it. In the *Beginner's Guide*, you'll learn how to get started with the board, both as a desktop computing system and as an embeddable platform for your makes. While called the 'beginner's guide', it will take you a long way towards mastering this platform.



Collins Complete Woodworker's Manual

Wood is a fantastic material for the maker – it's widely available and workable with hand tools, if you know what you're doing. That's a big if, but with a little practise, you can get a long way. It'll help you master the basics, and move on to more complicated work. Once you've got a bit of experience, *Collins Complete Woodworker's Manual* is one of those books that's great to have on your shelf – when you're starting a project, a scan through can help you plan the best ways of making it. □



FEATURE

How I Made

A REALISTIC FLAME

Recreating the candle experience with Arduino and NeoPixels

By **Keith Kelly**

What is a candle? Merely a dim light? Electric lighting has been common for nearly 100 years, yet even in the 21st century, we are still lighting candles. Why do we try to hold on to such a primitive thing of the past? We even sing about candles. Why do we give candles a melody?

To me, the smell of a blown-out match brings back memories of birthday parties as a kid. Drop the Duck Hunt gun. Wind up the yo-yo. Turn off the Lite-Brite. It's cake time. I hope the icing is buttercream. Brownie chunks in the ice cream.

If it's buttercream icing I'd like a corner piece.

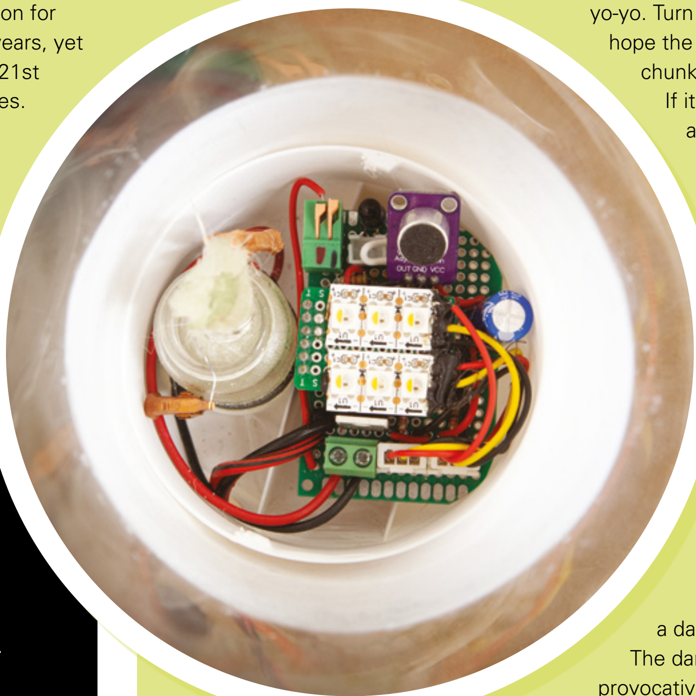
Blowing out a candle puts me in the birthday kid seat; the wisp of smoke verifies success.

As newly-weds in college, a candle was a cheap way to make dinner a bit more romantic. Thirteen years later, four children have pushed the candles to other rooms of the house.

I still feel candles light a room with romance and intrigue.

A candle is a throne on which a dancing flame refuses to sit still. The dancing flame is genuine and provocative, reminding us to seize the moment.

So, I bought my first Arduino, ran the Blinky sketch, then started making a candle to provide what I feel is the proper candle experience. Three years later, it's complete and better than I ever imagined.



Above
Look down into the candle to reveal the secrets

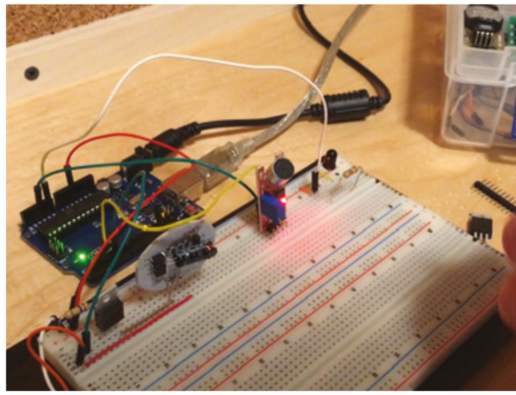
The Back Burner Prototyping Process

This project is a perfect example of strategically using the back burner approach. This candle took three years to make, but for most of that time, it was on the back burner (or rather, various shelves and drawers). I'd only work on the candle if I had inspiration or at least some specific idea. If not, I didn't force it; I left it on the back burner – sometimes for months at a time. When I had inspiration, I'd pull it out, spend a small amount of time implementing the idea, then return it to the back burner until the next time I had an idea worth acting on.

Is there such a thing as maker's block? If so, this is my way of dealing with it for non-urgent projects.

Left
Turn on the candle, using a match

Below
Breadboards are a great place to start electronics projects



KEY COMPONENTS:

- Arduino Pro Mini (brain)
- RGBW NeoPixels (flame)
- Infrared receiver diode (flame detector)
- Electret mic breakout (blow-out detector)
- Kanthal wire, glycerine, electricity (wisp of smoke)
- Scented oil (smell good)

I chose the Arduino Pro Mini (5V version) because it's tiny and cheap, yet still uses the ATmega328 – the same chip the Uno uses. This allowed me to do most prototyping on Uno shields, and occasionally create a Pro Mini version without having to modify the code.

THE LED CANDLE EXPERIENCE

Strike a match; light the candle; watch it flicker; blow it out. A wisp of smoke rises.

Ouch. Seeing a project that spanned three years of my life represented in so few words hurts my head bone. I'll proceed with highlights about the various stages mentioned above, and then I'll tell you about the notable iterations and their associated challenges.

LIGHTING THE CANDLE: A real candle's wick doesn't spontaneously combust at the sight of a flame, so neither does this. You must keep the match lit for roughly two seconds before the candle will light. The infrared diode watches for fire, while the Arduino holds the stopwatch. During these two seconds, the flame begins crawling up the match towards your thumb. If you hold the match at too sharp of an angle, the flame will reach your thumb too quickly, and you'll have to try again with a new match (or endure the pain while hoping for ignition).

> A real candle's wick doesn't spontaneously combust at the sight of a flame, so neither does this

IGNITION: Just as a real candle appears to flicker randomly up to its full brightness, so do the NeoPixels. Random LEDs, random timings, randomly pulse-bubbling up to their random pulsing target brightness.

The warm white LED on these RGBW strips isn't near warm enough to represent a flame. Mixing the colours as follows gave the perfect flame-like illumination to surrounding objects: RED 110, WHITE 100, GREEN 2, BLUE 0.

Pseudo-asynchronous (the ATmega328 is single-core) pixel animations coupled with multiple elements of randomness were key to making a realistic flicker. The following elements of the flicker are all random: the LED that animates, the brightness to which it animates up or down, and the animation time.

BLOWING IT OUT: Blowing air on an electret microphone (on a breakout board) causes the mic's signal to peak. The Arduino watches for this peak signal. When the peak is detected, the NeoPixels turn off with a quick wipe animation, as your breath would push a flame to the side. Then the smoking process begins. →

WISP OF SMOKE: 28-gauge Kanthal wire, clamped at 4 ohms, is heated for 1.2 seconds with a 12 V power supply (resulting in 3 amps of current running through the wire). The wire is wrapped around a fibreglass wick full of a mixture of glycerine and water (and a drop of scented oil). When the wire is heated, a small, convincing wisp of smoke rises into the air. And it makes the room smell pleasant.

RANDOM (RANDOM, RANDOM)

This may seem ultra-random, but it's actually less random than just normal random. Prior to this change, I felt I had injected randomness in all the right places, but the flickering was unconvincing. Something seemed artificial. I kept altering the numbers but couldn't nail it. So, I lit a real candle and watched it flicker beside mine.

This became obvious: a real candle is not as random as I expected. A real candle generally flickers within a certain normal range, and only occasionally flickers above or below that normal range. My candle was too random.

I solved this by first randomising the low and high values. Then, I fed those into the outer random function. This causes a random effect that's more concentrated in the middle. To bring the concentration dimmer (see dots above), I used a smaller value range (45–55) on the lower end compared to the upper range (80–255). You can see that this causes fewer brightness spikes, which oddly seems more random.

This improved the flickering effect substantially. In fact, it was probably the most important tweak of the entire candle.

ITERATION AFTER ITERATION

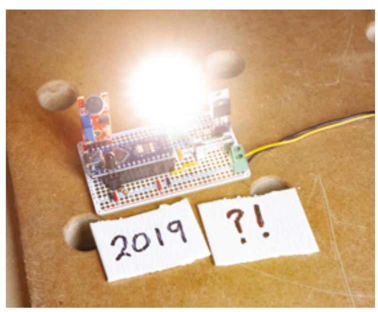
Make no mistake, I had many more iterations than I'm telling you about. But, these were notable for one reason or another.

As you'd expect, it all began with the first iteration on a breadboard. Though I was new to Arduino, I am a programmer and a seasoned Googler. Unfamiliar with NeoPixels at the time, I just used a 12 V MR16 LED I already had handy, and a MOSFET to control the 12 V LEDs. All worked very well! That is… well enough to boost my confidence enough to be painfully crushed by the second iteration.

Since I was on cloud nine already, I thought I'd go ahead and crank it to cloud eleven. For the second iteration, I bought an Adafruit Perma-Proto and began soldering. Perma-Protos are nice because they have the same layout as a typical breadboard, which makes for a dummy-proof transition… right?

I brought the soldered, Perma-Proto version to my real job and set it on my desk so my co-workers could ooh and ahh at my wonderful creation! This is when I realised that I was, without question, an overeager newbie. It worked great if I blew it out within a few seconds. But, if I left the LED on for any longer, the candle would become unresponsive and could not be blown out. Nor could it ever be brought back to life. I thought the Arduino must surely be faulty, so I replaced it, and it worked for a while, but ultimately the same thing happened. Then I blamed my soldering, which was particularly terrible at the time. I pulled out a new Perma-Proto, new components, and soldered everything together. And burned up more Arduinos. After burning up all five of my Arduino Nanos, I put both Perma-Proto contraptions of death into a drawer, and the five bricked Nanos in my '#fail' bucket. I was bothered and puzzled. The breadboard version worked; why didn't the soldered Perma-Proto version? I eventually rebuilt the candle using NeoPixels, which

After burning up all five of my Arduino Nanos, I put both Perma-Proto contraptions of death into a drawer



Right Why did these Nanos break? We will never know

Left There are many ways to make smoke with electronics

Below Simulating a flicker proved to be quite tricky

worked great! But I didn't know what caused the previous problem. Now, three years have passed, and I STILL don't know what was wrong.

Stop. I can't end it there. After writing the last paragraph, I pulled out a new Nano, the old Perma-Protos, and dug out the old code. That's right – I'm bringing a fire-breathing Perma-Proto back to life. To kill more Arduinos… in the name of testing.

It has been running flawlessly for 52 hours.

For the third iteration, I moved on to NeoPixels, and these made it possible to really fine-tune (obsess over) the flicker. I used Adafruit's NeoPatterns technique to handle the pseudo-asynchronous animations without interrupting the sensor readings. Over the next few months, I tweaked the flickering in several ways.

Randomness is key – but not always. Flickering (pixels going brighter or dimmer than the base value) needs to be random in the following ways: 1) which pixel flickers, 2) the flicker speed, 3) the brightness of the flicker. However, for the first part of the flicker animation (base brightness > target brightness), I found it better to remove the randomness and just get there quick. However, randomness was notably important when the pixel returned to its base brightness.

```
// reach target brightness quick
Strip1.Interval = 1;
// return to base whenever, as long as
it's by 10pm

Strip1.Interval = random(5,22);
```

I also found that the flicker brightness should not be fully random. It looked too robotic, so I concentrated the randomness at the lower end. See the boxout titled RANDOM (RANDOM, RANDOM).

The NeoPixel LEDs need to be as close together as possible. If the LEDs are spread apart, you'll see hard shadow lines on the wall from surrounding objects, which gives away the fact that this is not a candle.

Fun Fact: Iteration #3B In A Coffee Mug

This candle made its first debut in a coffee mug during a New Year's Eve party. It grabbed the attention of one friend, mainly because coffee mugs don't typically emit light. The rest of us were busy lighting the Christmas tree on fire.

FUTURE IMPROVEMENTS?

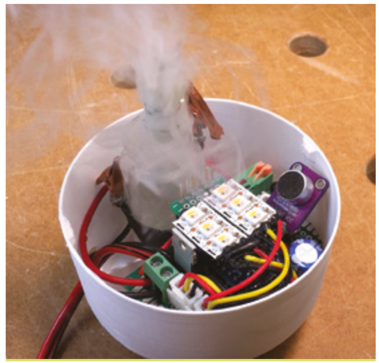
There are a few things I'm considering improving in the future.

Battery Power: Since I was submitting this as an Instructable, I ditched the 10.8 V Bosch batteries I had been using. They were too specific. I considered switching to a single 18650 battery, which can supply enough current – but there were some challenges I didn't want to get into (safety, charging). It was much easier to use a 12 V 5 A AC/DC supply and a fuse for the time being, and do battery power as an add-on later.

Add variable base brightness, erratic behaviour, and blow-out failures: The base brightness is constant. Though that's generally true of a real candle in a fairly consistent environment; sometimes a real candle goes slightly brighter or dimmer, or the flame starts bouncing around erratically for a bit. Also, when blowing out a real candle, sometimes you think you got it, but there's still that little spark that turns right back into a flame. These features are absolutely doable and would be great for v2.

Having the NeoPixels tightly concentrated together helps prevent those hard shadows. This may seem counter-intuitive if you're familiar with photography. Concentrating the light would make a hard light source, causing harsh shadows. However, in this case, I'm referring to the individual flickering LEDs. Let's pretend there's a single flower between the candle and the wall. A row of six LEDs that are spread out with space between each one will cause six shadows on the wall. When one flickers, its associated shadow will become more distinctive. On the other hand, the tight cluster of pixels brings the individual shadows closer together, causing them to be less noticeable.

Splitting the pixels into two strips drastically increased the fluidity of the flame. This allows multiple pixels to be animating at the same time. For example, a pixel in strip one may be halfway through dimming, while a pixel in strip two begins its flicker. In the final build, I used two rows of three pixels. Adafruit's NeoPatterns approach handled this well, as this is what it was designed to do.

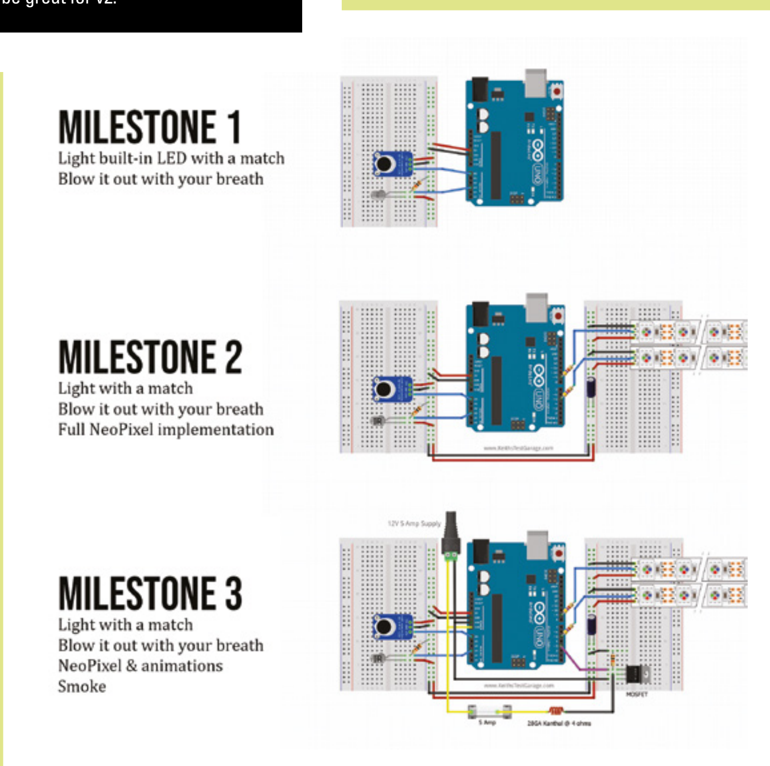


Above A rare occasion when smoking electronics is a good thing

I had no intention of including smoke until three weeks before the Instructables 'Faux Real' contest deadline, at which point I started on the third iteration – adding smoke. Long story short, while playing games with friends, I realised that one of them happens to be into pyrotechnics, so I asked if he knew an easy way to make a short wisp of smoke with a low voltage. A few days later, I went over to his place, he pulled out a bucket of awesomeness, showed me the basics of smoke generation, and gave me some parts to play with.

I needed the wisp of smoke to happen fast. Remember, I'm entering this thing into a contest. The last thing I wanted was to have a cheesy cloud of smoke starting to puff six seconds after the candle's blown out. I didn't even know what I'd use for a container yet. Should I really be spending time on smoke? I spent one afternoon to determine feasibility. Feasible? Yes.

I kept burning cotton, so I used fibreglass instead. To generate smoke quick enough, I needed to apply a lot of heat immediately, which quickly burned the cotton after two or three uses. Having made a few tiki torches recently, I had some spare wicks. Those wicks stay on fire for hours at a time. I pulled the cotton webbing back, using only the fibreglass. Bingo. The fibreglass wicks very well and won't burn unless the wick runs dry.



Left How the electronics evolved over time

While I mostly had the technical side of things worked out, I needed a thing to put everything in. In the fifth iteration, I started looking for a container. I was stuck. I couldn't minify the internals without knowing what size container they'd go in. What if I found a container that was short and fat? Tall and narrow? The lack of container was officially holding up this project.

Finding a container for this thing was by far, without question, the most difficult task of this entire build. I wanted a proper glow on the wall and surrounding objects, and therefore I needed a container that provided proper diffusion. In addition, the electronic components must be hidden. Nothing around the house seemed to work. With 3D printing, I could achieve the diffusion I was after, but the match flame would melt it.

Unaware of the project at hand, a friend gave us some tall candles because I was struggling with this. The size was right. I wanted that burned-down look that some of these had: the flame deep down low, and the inner walls of the glass coated in wax. Boring out the centre seemed like the best option so far, but I needed all the inside space I could get, and didn't know how to bore precisely.

> Finding a container for this thing was by far, without question, the most difficult task of this entire build

Got it. Instead of removing wax, I added wax. So, I started with an empty glass jar, then chopped up a single candlestick and dropped the chunks into the jar. I melted the wax by heating the jar from below using my lathe. Once the wax was clear, I pulled out my welding gloves and held the jar almost horizontally, slowly spinning it while the wax cooled. This created the perfect, thin coating of wax that I was hoping for.

WANNA MAKE YOUR OWN?

The code is on GitHub! Since the whole project can be a bit daunting, I split things up into three milestones, and committed code for each. Milestone 1 is quite simple – by the end, you'll be able to illuminate the built-in LED with a match, and blow it out with your breath. Milestone 2 adds the NeoPixels, while Milestone 3 adds the smoke.

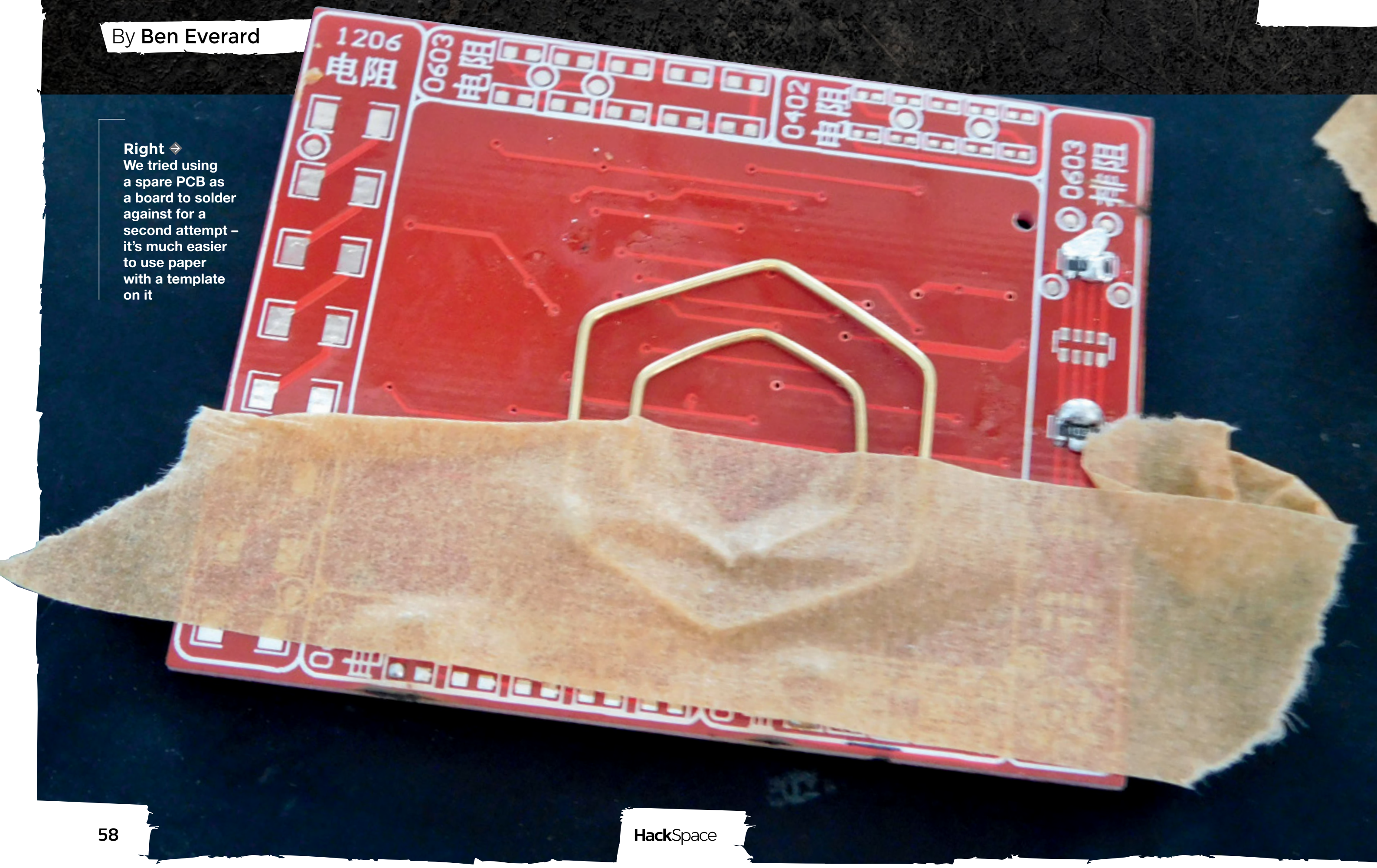
You can put your own spin on it and make your own. Several people have commented on the video with ideas about how to make this even more realistic. If you have ideas, implement them, record a video, and send me a link!

Was it all worth it? Totally! But not for the candle itself. I mean, just go and buy a real candle. This was a project of intrigue. I *really* wanted to make it. Because of that, I overcame challenges far more quickly than if I only *sort of* wanted to make it. □

IN THE WORKSHOP: Learning with art

Developing our technical skills by making beautiful(ish) things

By Ben Everard



Right We tried using a spare PCB as a board to solder against for a second attempt – it's much easier to use paper with a template on it

We've been eyeing the work of Jiří Praus and Mohit Bhoite with envy for a while now. We've featured both of their work in the Top Projects in previous issues, and they make free-form circuit sculptures using brass wire to connect components together, in fully working 3D electronics objects of beauty.

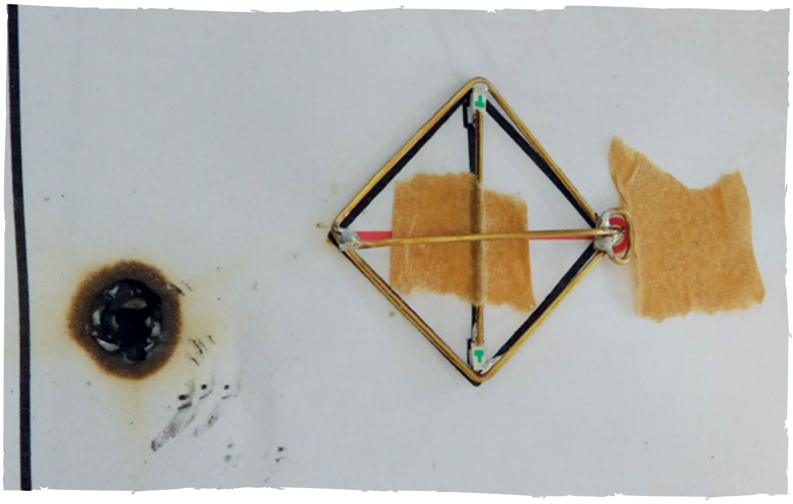
This month we've had a gas-powered soldering iron-cum-hot air gun in the HackSpace magazine workshop, and we thought we'd put it through its paces on some free-form soldering. This wasn't just about testing out the iron – we also wanted to know how hot-air soldering would work for free-form soldering.

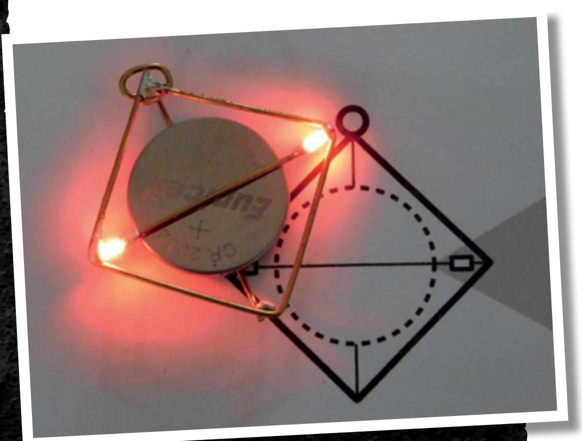
Jiří Praus has written some excellent Instructables for how to recreate some of his builds. We thought that the simple LED jewellery was a great starting point. The essence of this method of building circuits is building up your circuit according to a paper template. In each step, you bend some brass rod and solder it on to build up your final form. These paper templates are available for download. All you need are some 1206 LEDs, some thin brass rod (available from model-making shops and online – we used 0.8 mm diameter), and a CR2025 battery (though you could make your own templates to work at a different size).

We wrapped some electrician's tape around our plier jaws to prevent marks on the brass.

Jiří suggests using double-sided tape to hold everything in place while soldering, but we didn't have any in our workshop, so we used regular sticky tape instead. This worked to hold the brass in place, and we used tweezers to solder the LEDs. We suspect it would have been easier with double-sided tape, but it certainly works with normal tape.

We quickly discovered that the key to free-form soldering is accurate bending, as there's very little leeway if everything is to fit in place. 1206 LEDs might be considered huge by surface-mount standards, but they're still small when working with bent wire. If you go off the template even a little bit, it becomes very hard to make everything fit together.





Above ⬆
Paper burns, so be careful!

Left ⬅
The four-way joint at the top of the piece is by far the hardest to solder

MEASURE TWICE, BEND ONCE

We can't stress enough how important this accuracy is, and it takes a bit of practice. It's not just a case of measuring accurately because as you bend the rod, this stretches the outside while compressing the inside and this, plus the bend radius which will vary depending on how you bend it, has a noticeable effect on the length of each side.

The battery is held in place by the bent brass rod, and there's not much give in this, as we discovered to our cost. Our first attempt busted its seams when we put the battery in – it turns out that LEDs don't have much structural strength. With another attempt and more attention to detail, we created a working circuit.

So, back to our key question – how does hot air work for free-form soldering? Not as well as we'd hoped. Part of the problem is that the brass rods conduct heat away from the joint so well that you really need to dump quite a lot of heat into the joint to get the solder to melt. This overcooked the LEDs on a few occasions. Perhaps, with a better temperature control method such as a reflow oven, we'd have had better luck, but we wouldn't recommend it with a hot-air gun. We did manage to make one of Jiří's square jewellery pieces correctly, but when we attempted again using a regular iron, it all went much smoother.

These little jewellery circuits are a great introduction to free-form soldering. They're easy enough to get started with, don't require any special tools, are fairly quick to build, and the bright light from the LEDs obscures any slight wonkiness in the structure. →

FEATURE

Brazing
A sculpture for the garden

It may come as a surprise to you, dear reader, that we're not all-knowing maker superheroes. HackSpace magazine is put together by a team of enthusiastic makers, and together we've got a wide range of skills and experience, but individually we each have our specialisms. We often learn skills as we're putting the magazine together. Such was the case with Andrew Lewis's article on Brazing in HackSpace magazine issue 23.

I did a small amount of brazing back in my school days when we had to make a candle-holder as part of the design and technology lessons. However, my memory of how to do this has faded in the intervening two decades, so I decided to get out my blow-torch and see what I could achieve.

Below ↓
Our brazed flower – still in need of a bit of clean-up – in the flower-bed

Andrew's tutorial covered making a tool-holder out of coffee cans. It's a great project and ends in a useful addition to your workshop. However, I wanted to take the same technique and make something different. We recognise that most people don't have exactly the same needs as us – so, when we create tutorials, we try to show a technique, tool, or skill that you can apply to a wide range of areas, and not just copy what we make in the magazine.

I wanted something that would require a lot of brazing, so I could really get to grips with the technique. I'd recently attended an exhibition of garden sculpture and came back inspired to build something to liven up the outside space. Now's a perfect time for such things as the plants are dying back and everything's looking a bit bare. I decided on a simple design that should both liven up the garden and put my brazing to the test – a flower made out of chain and coins.

LEARNING WITH STEM

The stem of the flower was to be made of chain with each link brazed solid, then the head of the flower made out of 1 and 2 pence coins. The only important thing about the chain is that it wasn't galvanised steel. You can braze galvanised steel, but you have to be a bit careful with temperature as it can give off toxic fumes, so it seemed sensible for my first project to sidestep this entirely.

I purchased a suitable chain, some brazing rod, and flux, and I was ready to set to work. I already had the tools I needed – a MAPP gas blow-torch, a fire-brick (for a hearth), and a pair of pliers to ensure I don't burn myself, but all of these are easily available if you don't have them. I had thought that you needed an oxyacetylene setup for brazing (as I'd used many years before in school), but, as Andrew

Left
Brazing joints without oxidising other joints proved to be the main challenge of brazing the chain

showed in his brazing article, this isn't necessary for simple work.

Perhaps the most unusual thing about brazing the links together on a chain is how close together subsequent joints are. The flux from one joint flowed into the next, and joints easily became oxidised from the heat of earlier joints. This meant that we had a hard job keeping everything clean enough for the molten bronze (I used Sifbronze as the filler metal) to take hold.

The flux from one joint flowed into the next

It turns out that the shape of chain links makes them really hard to clean. After various attempts with wire brushes and sandpaper, I found that diamond-carving bits in a rotary tool are the best option for cleaning out the links before brazing. A fortunate discovery, because I certainly don't have the patience to poke sandpaper in more than a few chain links.

The process for brazing is pretty simple (head back to Andrew's article for a detailed explanation): you heat the brazing rod slightly and dip it in flux. Then you heat the joint and apply the brazing rod until it melts and flows into the joint (much like solder does). Once you've brazed a few joints, quench the lot in water, and the flux cracks off. There's a bit of a knack to getting the right amount of heat into the joint in the right places to help both the flux and filler flow.

BLOOMING MARVELLOUS

Once I'd got the stem of the flower together, it was time for the flower-head. I used 1p and 2p coins because they're nicely sized pieces of metal and I'm cheap. Despite their common name as 'coppers', they're not actually copper, they're copper-plated steel, so we can use the same Sifbronze brazing rod we used for the chain (had they been actual copper, we'd have needed to use a lower-temperature brazing rod).

One difference between brazing and welding is that, because brazing operates at a lower temperature, you're more prone to unbrazing close-by joints when you braze, and this makes it quite hard to make 3D sculptures. In other words, we had to have a way of holding the whole flower-head in place while we brazed the coins together. After a bit of wedging, jamming, and thinking, I decided to stick with the simple choice and have a flat flower-head rather than something more complex like a rose or tulip.

I laid the coins out on the hearth and went around brazing each joint. Halfway through I realised that I'd included an older coin that was made of copper which half-melted, but this didn't cause a problem.

The final part of the process was joining the coins to the chain. I couldn't braze these on – at least not using the same Sifbronze as before. I used a lower-temperature, aluminium-based brazing alloy that I could use without melting the higher-temperature Sifbronze joints.

I'll be honest. The end result isn't everything I hoped it'd be from an artistic point of view, but that's life. Sometimes the visions in your head don't translate into the real world. It was, however, a fantastic learning experience. □

HackSpace magazine meets...

Sam Underwood

Meet the man making maverick music machines

Weird musical things, art installations, mind-bending sonic sculptures stimulating to the eye and to the ear.

Sam Underwood is a performer and a maker, turning whatever he can get his hands on into unique musical creations. He's had work featured in the hallowed pages of HackSpace magazine, the South Bank Centre in London, and the Golden Lion in Todmorden.

We spoke to him from the flooded banks of the River Severn about methods, music, and how you don't need to be in control of every aspect of the process to call yourself a maker. →

Above
Musician, sculptor, artist, innovator: Sam Underwood

Above
This is part of the Mammoth Beat Organ, a modular synth made of moving parts rather than electrons

HS How do you describe what you do? Are you more of a musician or a sound artist?

SU In most respects, I'm more a musician than I am a sound artist, but in many ways, I'm neither. In many ways, I am a musical instrument designer. I do sometimes use those myself, such as the Mammoth Beat Organ, but I also do a lot of pure research on different methods of making sound and a lot of stuff in the lab like that. And then I produce instruments to commission. At the moment, for example, I've been commissioned to do further research into feedback clarinets, which I started to dabble with, and then somebody said, "Oh, I need you to concentrate on this project, here's a bit of money, let me know how you get on."

HS How does that work?

SU I'm working with a person who has a year-long funded research post themselves, and they are already working with a clarinettist doing related stuff; both of these people saw the work I was doing with the feedback clarinet, and that resulted in what you might call seed funding; it's not a huge project yet, but it's enough money to buy bits and do it properly, test whether there's something of interest there, potentially give that instrument to the clarinettist to try out, those sorts of levels of development. We'll see at that point whether there's something good to be had out of that or not.

HS Is that another mechanical project?

SU No, it isn't. It uses audio feedback basically. My work over the last five years has predominantly been acoustic, mechanical instruments. There are a lot of aspects to making those sorts of instruments that will veer off into other areas.

The other commission that I'm working on at the moment is to build an acoustic modular synth.

I've been commissioned to build a musical instrument, record an album with it, and release it on a label. And the label have commissioned it entirely. It's going to be my instrument, in the end, to own and play, so, therefore, there's a lot of time going into building something really decent. It's basically a modular synth format but all of the modules are acoustic sound-making or shaping devices.

HS If you say the phrase 'modular synth' to most people, at least those who understand it, they immediately think of electronics. How come you don't? What's led you to physical, acoustic instruments rather than electronics?

SU There are a number of aspects to that. One is that I started out mostly building synthesisers from scratch. I got into that from a route that most people do, which is circuit bending. I did a lot of circuit bending, to the point where I could design some circuits and build some synths, and then I think really I plateaued in terms of what I was able to make with my knowledge that I thought was interesting. I kept coming up against barriers in terms of the functionality that I wanted to have in a synth, but I had a lack of understanding of the electronics to make that happen.

I then started applying many of the principles of electronic music to acoustic instrument design. And finding that with a mechanical sequencer, for example, I can get it to do what I want it to do without worrying about some weird thing that's going on in the electronics inside it. I can physically adapt a thing that sticks out of it to make it do something different.

> "In most respects, I'm more a musician than I am a sound artist, **but in many ways, I'm neither**"

I'm not really the sort of maker who can just draw something and know that it's going to work. I tend to scribble a version of something, and go and build a rudimentary version of it one way or another. It might be that I'm using rapid prototyping, or it might be that I'm chopping up some bits of wood – put it together, test it, then realise what the problems are with it, fix it, re-work it, and keep doing that a couple of times until I'm happy with it. The Mammoth Beat Organ has gone through that process and continues to go through that process. We [Sam and co-creator Graham Dunning] meet quite regularly to adapt the way that it works.

Firstly it was a means to an end, where I could physically change something, and it would change the sound. But then I realised two things: one is that it's immediately much more visually engaging and obvious what the performer is doing, which is something that I find more engaging when I'm at a gig – I like to see that somebody's doing something, so that's helpful.

And also, I soon realised that it's a relatively lesser-exploited area. It's much, much easier to go and buy a sampler, looper, etc. off the shelf than it is to build your own out of mechanical systems. And so fewer people do it, which means it's possible for me to stand out more as somebody who does that sort of thing. And then I plough hours and hours, and years and years, into understanding musical systems and acoustic systems, and things like that, to differentiate my work, and that's how I've ended up where I am.

HS Ah, the old 'hours of hard work' trick! Have you always been an instrument maker?

SU No, I started a web design company when I left university with two friends. →

At that point, I was very much making electronic music. I would perform live, with a hardware setup, but it was always pushed to the fringes of what I was doing. At one point our business got big enough to have a load of full-time employees, and at that point, you're just working your ass off running a business.

You don't really have much free time to do anything creative, beyond what you're doing in your business. It all got pushed to the sidelines for years. I would occasionally do gigs if I could muster enough of a set to do that. It really got to a point where me and my colleagues, after seven or eight years, asked ourselves, 'what are we doing this amount of work for, without a lot of creative aspects anymore', and we downsized. We went back to just two of the directors of the company, and it was a pretty massive moment in many ways. Emotionally it was quite taxing, but that freed up time for us to do in our spare time the things that we did prior to running the business.

Since then, I got into synths, circuit bending, and building synths, and using those in my live sets. That was maybe 16 years ago. In the end, having downsized to just two, I left the company to do what I do now full time; that was about ten years ago – building musical instruments for myself and for other people.

It was a leap into the unknown, but it was one that I took very steadily – that tends to be my approach. Everyone knew I was leaving for about four or five years before I left, and I saved money for that four or five years so that, in the period when I didn't have any work, I'd be able to live. It's worked out OK, because I've managed to sustain it.

Nowadays it's much more a self-sustaining thing, but it takes a while to bed in.

> "Everything that I do is driven by **the physical requirement of the thing**"

HS There seems to be a philosophical divide between those people who can jump in on Monday and say 'this will be a success', and the type of person who does things as gradually as possible.

SU I do actually provide this as a piece of advice to anyone thinking about setting up a business: when you've got very few constraints, just going for it is a perfectly valid approach. The idea that business people out there know what they're doing it very overrated. I think most of them are just trying something out, seeing if it works or not, and then changing it if it doesn't work, and carrying on if it does.

HS Your work all looks completely different. Every piece has a different aesthetic, different materials, a different type to everything. Is that something you do on purpose?

SU I think it's something that works against me some of the time, to be honest. There's definitely something to be said for having a house style that people can buy into. I definitely don't have that. It isn't something I do deliberately… everything that I do is driven by the physical requirement of the thing. The fact that the Mammoth Beat Organ is made out of the quality ply that it is because, as a base unit, it needs to be able to run these large machine bearings that give a rigidity and a structure to the thing.

Something like the Giant Feedback Organ – it was really about what system exists out there. That often informs what I do: what's already out there. It means I don't have to commission somebody to build me some pipes at the right scale. Where can I get them and are they light enough? →

Left
Everything Sam builds is designed with the sound of the finished product in mind

Left Over the years Sam's built up an enviable collection of tools for working with wood and metal

In the case of the Giant Feedback Organ, I knew I needed to get them on the roof of my van, and I knew they had to be available in various different sizes. If it achieves the sound goals and the system goals, I'll go with pretty much anything visually. In many ways it would have been lovely for the Giant Feedback Organ to be built out of beautiful straight tubes from something else, but A) there wasn't the money, and B) you just can't do that up from nothing; you have to scale to that sort of change.

HS What does your making process look like?

SU Sometimes my work involves producing a working version of a thing that I then do technical drawings from, which then go to either a machine shop or I machine them. Most recently, this has become a lot easier because of STEAMhouse. It will tend to be that it's not always me who makes the individual parts for a thing, but I do end up doing all the final assembly.

HS You only add value where you can add the value; nobody cares whether you've taken a lump of copper ore and melted it down and made pipes with it…

SU No. I think for some artists that is what they choose to focus on, right down to that sort of level. I'm very much more centred on what it does acoustically as an object, and how effective it is as a sound-producing device, than I am on worrying about whether I've handmade a thing or not.

There's a guy who made the Sharpsichord, which is a sort of pin-barrel harp that Björk featured some years back. Henry Dagg is his name, a remarkable artist.

I feel a similar sense of dread to what Henry describes, but he and I address it in different ways. He describes how he gets to the point where you're building something that's going to have 128 notes, and you work out how one of those notes is produced. And then you have this sudden moment of dread when you realise you've got to make 127 more of them.

He hand-machines all elements of the instruments he builds. At that point, I'm going to Illustrator to design myself the parts properly, get them manufactured, and then a bag of parts turns up that I put together at a later date.

I'm very happy doing the handmaking for the first section – but I'm not going to spend five years cutting widgets.

HS How has working at STEAMhouse made a difference?

SU There are a lot of machines there, processes that were shrouded for me until I got to STEAMhouse. I would get some stuff CNCed, but I never really knew what that meant. They'd come back, and they would be OK, or sometimes they would not be OK, and I wouldn't understand why, but now I do. I'm able to design to the process much better than I was able to do, which is really a big change.

The other thing is that there are technicians there for every department. If I'm wondering how to approach a thing, I can go to the metalworking technician who has spent years in the jewellery quarter making jewellery, and find out how to solder different types of metal together.

Ruth Claxton, who was one of the people instrumental in setting STEAMhouse up, is part of a group that has tried to draw together artist-friendly manufacturers in the West Midlands. They're called Workshop Birmingham.

What that allows is that not only are you dealing with an understanding of the process at STEAMhouse, but you're also able to use it as a conduit for approaching third-party companies who do other kinds of manufacturing that aren't available at STEAMhouse, but address them in a way that makes sense to them and not in a way that's just an artist going, "Hi I know nothing, I need to make a thing". It gives you a much better framing for what you're doing.

HS Finally, what are you up to right now?

SU Part of the ebb and flow of my work is that I tend to get very busy from spring onwards into the summer season. I tend to build a lot of pieces for artists and sometimes for commissions of my own for the summer season, and I treat this time of year as more in the way of hardcore research and some music recording. Lock the doors, hunker down, and get things done. □

Right
Keep an eye on mrunderwood.com for news of gigs in a UK near you

IMPROVISER'S TOOLBOX

COTTON BUDS

Put the most misused product to some good use

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.

You can find pretty weird things in the aisles of supermarkets these days, but none of them are as bizarre as cotton buds. These are perhaps the only products that are used primarily for the one task that its manufacturer warns against. Polish inventor Leo Gerstenzang was struck by the idea of a mass-produced swab when he saw his wife preen their young child using cotton balls stuck on the ends of a toothpick. His safer, sanitised version was made of wood, and was marketed as Baby Gays in 1923.

Their design (and the name) has advanced significantly since the 1920s. For starters, the wooden sticks were first replaced by paper spindles that weren't as threatening to the ears. More recently, plastic has become a popular material choice for spindles. Designing the shaft is a delicate process since care must be taken to ensure that it doesn't puncture through the cotton mass at the ends. The application of the cotton itself is an involved and complex process that involves a series of workstations.

Back when cotton buds came into existence, they were meant to be used for baby care and unfortunately, no one discouraged putting them inside of ears. While the company continued to endorse the buds as being useful for cleaning out earwax, the medical community never agreed. It took over 50 years for manufacturers to explicitly warn against sticking them inside of ear canals.

Scientists say that despite the warnings, we continue to twist the cotton-wrapped twigs in our ears because it feels good. The ears are lined with sensitive nerve endings, which, when tickled, triggers our pleasure centres. Another reason, according to dermatologists, is that using cotton buds traps us in an itch-scratch cycle; the more we use them, the more our ears itch, and the more we use them. Our primary reason for getting addicted to cotton buds is to clean out earwax.

> "BACK WHEN COTTON BUDS CAME INTO EXISTENCE, THEY WERE MEANT TO BE USED FOR BABY CARE AND UNFORTUNATELY, NO ONE DISCOURAGED PUTTING THEM INSIDE OF EARS"

However, many dermatologists agree that earwax is like tears. Our body produces it to protect the ear canal. Even those dermatologists who don't subscribe to this belief, still agree that cotton buds are a terrible thing to use to clean the ears, and their design and construction actually does the exact opposite; it tends to push wax inward, toward your eardrum.

The manufacturers though are doing their best to discourage people from sticking the buds into their ears. The original manufacturer of the cotton swab, now known as Q-tips, Inc. advertises multiple uses of the swabs in order to broaden the product's appeal. If you're looking for some inspiration, here are some from the maker community.

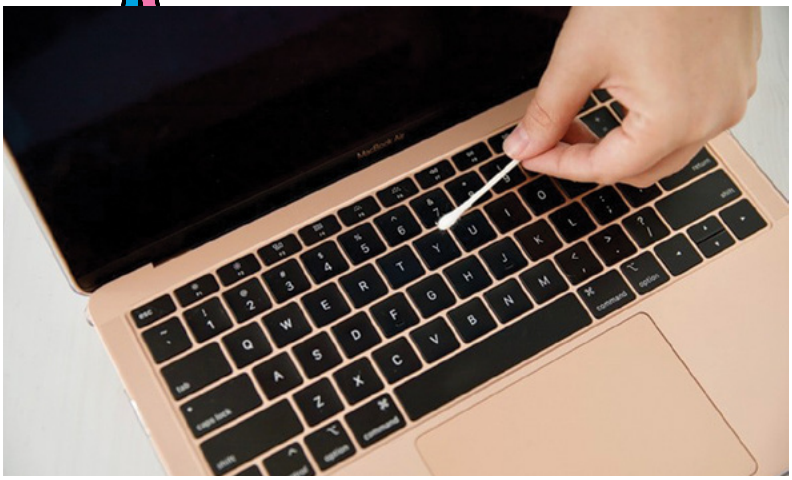
MULTIPLE CREATIVE USES

Jill is an Emmy Award-winning TV producer who's now a stay-at-home mum for her four kids. Her blog features useful and practical solutions to help homemakers successfully master their realm. No wonder then that she has a post to help you appreciate the versatility of the cotton bud, where she shares eleven practical ways to use the swabs, for everything from fixing make-up gaffes to cleaning hard-to-reach areas. The first few tips will help you rectify some of the most common types of make-up mishaps, such as smeared eye shadow or removing excess mascara. In the same vein, you can also use the buds to fix paint job gaffes, including scuffs and scrapes. She's also used the tiny little wands to clean electronics, as well as the vents in a car and also to remove lint from a hair-dryer. If you have a stuck zipper, Jill suggests applying a small blob of Vaseline or cooking oil to a cotton bud that you can then use to lubricate the zipper. You can also dip the cotton bud in a jewellery cleaning solution to shine the hard-to-reach areas of pendants and brooches.

Project Maker
JILL NYSTUL

Project Link
hsmag.cc/Si2B75

"If you have a stuck zipper, Jill suggests applying a small blob of Vaseline or cooking oil to a cotton bud that you can then use to lubricate the zipper"



Left
Dip a swab into isopropyl alcohol to sanitise and clean the muck off all your electronics

COTTON SWAB ACCESSORIES

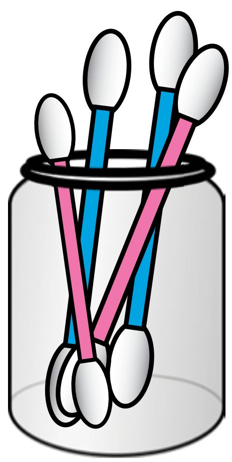
Just by looking at them, you can tell that cotton buds would lend themselves to some nice arts and crafts projects. Mona Christy runs one of the top 100 craft channels on YouTube, and in one of her videos uses the buds to create some nice-looking accessories. To create the bangles, she first dabs some acrylic paint on both ends of the cotton buds. She then applies a thin layer of white glue to seal the paint and protect the cotton from water. Once they're dry, she uses scissors to chop off both the painted ends. She does this for about two dozen cotton buds. These are then pasted to a bangle with a glue gun, and then decorated with some lace. Similarly for the headband, she glues a handful of painted cotton bud tips to a circular piece cut from a foam sheet, together with some pearls, before pasting it onto a headband that's been wrapped with a satin ribbon. Creating the pendant is similar as well, and involves cutting a tear-shaped piece from the foam sheet onto which she glues some painted cotton buds. Attaching this pendant to a chain is the most intricate part of the process.

> "To create the bangles, she first dabs some acrylic paint on both ends of the cotton buds"

Project Maker
Mona Christy

Project Link
hsmag.cc/6WK3Fa

Left There are loads of creative ways you can use cotton buds in jewellery, these are just some examples



LAMB FRIDGE MAGNET

Project Maker
Fab Art DIY

Project Link
hsmag.cc/6r3Yh9

If jewellery isn't your thing, follow the lead of the creative minds at Fab Art DIY to use the cotton buds to create a cute lamb. Sheep are white, so you don't really need to paint over the buds – you can use them as they are. Start by drawing a large oval and a small oval on a piece of white cardboard and cut them out. These will serve as the lamb's body and its head. Cut the cotton ends from the cotton swab, along with a small portion of the shaft. Glue these onto the large oval and a select few on the top of the lamb's head, including two for its ears, leaving enough room to draw on its face. Use a pen to draw the eyes, mouth, and nose on its face. Finally, glue two clothes-pins to the back of the body to make it stand. ◻

Right You can glue a magnet on the back of the body of the lamb to use it as a fridge magnet

TINY BOW AND ARROWS

Project Maker
Maiz Connolly

Project Link
hsmag.cc/c0pU9m

Right Maiz says these tiny bow and arrows work well as birthday gifts, especially for pre-schoolers

Maiz is a professional photographer and a mother of three who has yet another crafty way for using cotton buds. She uses the bud as a tiny arrow that can shoot from miniature DIY bows. To create the bow, take a popsicle stick and cut four small notches at the edges using a sharp knife. Then soak the stick in water for an hour until it becomes malleable.

A length of dental floss wrapped around the cut edges a couple of times on the slightly bent popsicle stick completes the bow.

The arrows are created by clipping one end of the cotton bud. Depending on the length of the cotton buds, you can even get two arrows from one bud. It takes some practice to shoot the tiny arrow, but once you get the hang of it, you can shoot these cotton bud arrows quite far.

This technique for using water to make wood bendable can be exploited for some really interesting makes beyond this one. It's a little skill that can have some big results. ◻

INVENTING MUSICAL INSTRUMENTS

with Bela and BeagleBone

MUSIC HACKING **IS HUMAN**

Humans love to hack sound and experiment with music. Classical music mainstays such as Stravinsky, Debussy, and Strauss were considered avant-garde and controversial in their time. Every instrument was once a strange invention – even instruments as familiar as the violin were created by people who made use of new techniques and created new tools to iteratively shape them across the years into the familiar forms we know today.

When humans get their hands on any kind of new technology, we like to mess around with it. Take, for instance, the humble magnetic tape recorder, a sound recording technology that became popular in the 1940s. People playing with this new technology created a new way of making sound, called 'musique concrète'. They recorded sounds, speeded them up, slowed them down, turned them upside down, sliced them up with scalpels, and stuck them back together again with sticky tape. The artists and engineers tinkering with new technology spawned a whole new wave of techniques and sounds. To most people, the music they made sounded pretty terrible (you can listen to some early musique concrète on YouTube if you want to judge for yourself), but the techniques and concepts were incredibly influential.

Lots of artists, experimental composers, and mainstream musicians used these ideas, including the Beatles and Pink Floyd who directly worked with musique concrète pioneers such as Schaeffer and Stockhausen. Listen to the opening bars of *Tomorrow Never Knows* by the Beatles or the original *Doctor Who* theme tune, arranged by Delia Derbyshire from the iconic BBC Radiophonic Workshop, and you'll hear the unmistakable sound of musique concrète.

"BECAUSE WE WEREN'T EXPERTS, WE DIDN'T KNOW WHAT WE SHOULDN'T BE CAPABLE OF DOING"

BBC RADIOPHONIC WORKSHOP ENGINEER

MODERN MUSIC **HACKING**

Just as the emerging accessibility of magnetic tape inspired an exciting new wave of electronic music possibilities, today we are surrounded by affordable and accessible electronics we can tinker with to make exciting, terrible, and strange new sounds. Many makerspaces across the world have music tech groups where sound hackers can learn from each other and share their latest techniques including collectives like Hackoustic, who organise excellent bi-monthly show-and-tell events at a community space in London. There are also many incredible resources on YouTube, with people like Sam from the channel Look Mum No Computer not only making strange and wonderful music machines, but tearing down the tech inside them and giving tutorials on how to get started yourself.

Pretty much every single board computer or microcontroller on the market today has people playing with them to make sound, from children using block code and buttons to make simple square-wave bleeps and bloops – including the MINI.MU glove I made for Imogen Heap and Pimoroni – to art collectives and engineers collaborating to make giant interactive public art installations with sensing systems and complex sound synthesis.

Once you've mastered making bleeps and bloops on a simple prototype board, you might want to think about designing something more sonically and technically complex. In my work making music machines, I've played with many systems that use different combinations of hardware and software, including the top-notch sound libraries on the powerful new Teensy, the plug-and-play capacitive Touch Boards by Bare Conductive, which are great for stress-free installations, and the solenoid-powered robotic music machines from dadamachines.

In this article, I'm going to take you on a tour of one of my current favourite ways to make an advanced musical instrument with embedded technology: the Bela system. Bela is an add-on for the BeagleBone single-board computer that uses open-source software and hardware specifically designed for making ultra-responsive, beautiful sounding instruments. If you're ready to move on from bleepy bloopy square waves, it's a great place to start.

Bela is made in the Augmented Instruments Lab, part of London's Queen Mary University. The lab is headed up by Dr Andrew McPherson, an electrical engineer who is also a composer and classically trained musician. At the Augmented Instruments Lab, they design open-source hardware and software made for music, create experimental instruments, and run events, including a recent hackathon that challenged participants to make "absurd musical interfaces, questionable sonic interactions, and unworkable music designs". Bela is the result of this combination of technology, music, and imagination – which is why it works so well for making modern music machines. →

BEAGLEBONE: **ESSENTIAL STATS**

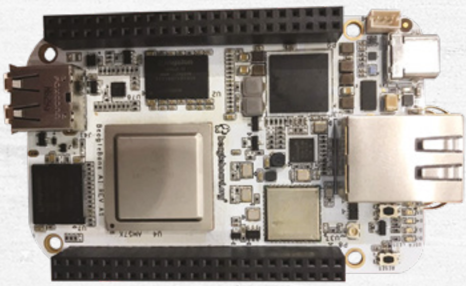
Before we get to know Bela, let's introduce the board it's based on. Bela and Bela Mini are based on the BeagleBone Black and the PocketBeagle, open-source single-board computers designed for interacting with the physical world – think robotics, autonomous cars, and sensing systems.

The BeagleBone Black and the PocketBeagle are actually part of a family of open-source hardware boards and add-ons led by the BeagleBoard.org Foundation, a non-profit organisation in the USA. As well as the popular BeagleBone Black (designed to fit into an Altoids tin) and the tiny PocketBeagle (designed to fit into a mini Altoids tin), the family also includes the BeagleBone AI (designed for speedy machine learning) and the BeagleBone Blue (designed for robotics). You'll often find the BeagleBone in professional and academic projects that require a high level of accuracy such as drones, robotic rovers, and CNC control.

BeagleBones are especially well-suited to projects that require handling high-speed sensor data and precisely controlling physical outputs such as motors, LED arrays or, in the case of Bela, sound. This is because of the beefy system on a chip (SoC) it uses. At the heart of both the BeagleBone Black and the PocketBeagle is an SoC called the TI AM3358, which is made up of an ARM processor running Linux plus two separate microcontrollers, called PRUs, made to handle timing-critical tasks. This SoC is mainly used for high-speed, precise industrial applications, so having them on board a single-board computer means we can do some pretty powerful things with it.

One thing you'll notice about the BeagleBoard family is how many pins they have for their size: the BeagleBone Black comes with an impressive 92 connections, including eight PWM outputs, seven analogue inputs, four timers, and a whopping 65 GPIO pins. You'll also find plenty of options for communication with three I²C buses, two CAN buses, two SPI buses, and five serial ports. These vital statistics mean they're not the cheapest board out there, but if you've got a project that needs a bit more grunt, they could be worth having a look at.

Most single-board computers and microcontrollers have a range of add-ons for specific tasks. Raspberry Pi add-ons are called HATs, and Arduino has shields, but the BeagleBone add-ons are called capes. Bela is one of these capes, using the high-speed capabilities of the BeagleBone's chip and turning it into a way of making super-responsive instruments.



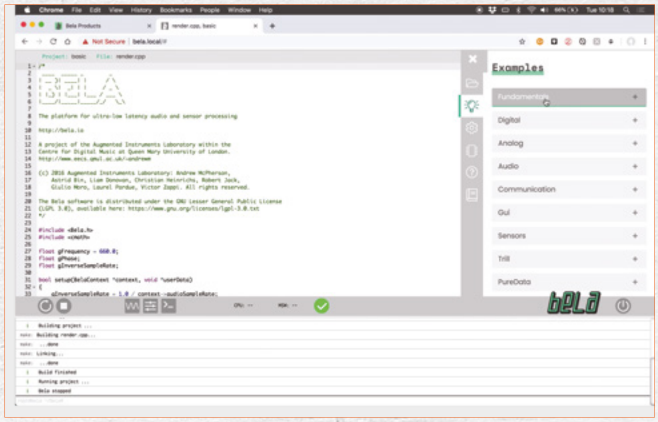
WHAT MAKES BELA SO COOL?

There are many awesome boards out there that you can make music with. You can dip your toes in DIY music tech with the classic Arduino 'theremin' project, experiment with the tiny but powerful Teensy, or if you're looking for a Raspberry Pi project, you can run the wonderful live coding system Sonic Pi. Each system has its own advantages and quirks, but there are a couple of things Bela does that make it extra special for embedded audio projects.

RESPONSIVENESS

As a sound hacker, one of the problems you'll need to tackle when trying to make a satisfying digital instrument is latency. When you play an acoustic instrument, such as a guitar or a violin, you'll hear a sound almost instantly after it's produced. However, digital audio has to be processed by a computer before the sound you've designed comes out from a speaker. That causes a lag between touch (or gesture control, or light signal, or whatever type of input your imagination decides should be triggering your audio) and you hearing the actual sound. We're used to physical instruments sounding as soon as we play them, so digital instruments can sometimes feel stilted and unnatural unless we solve that pesky latency problem.

The Bela team created a powerful audio environment by combining Linux with Xenomai, which lets you prioritise certain tasks, making sure audio-related tasks get processed before any general system tasks. Remember that BeagleBone SoC with a processor running Linux *plus* two separate PRU microcontrollers that I told you about earlier? Well, those PRUs handle timing-critical audio processing to shrink the latency from action in to sound out – 1 millisecond from audio in to audio out, or an outrageously quick 100 microseconds from analogue in to analogue out. Compare that to an instrument using an Arduino and a Raspberry Pi, which would have around 19 milliseconds of latency, and you can see why Bela is exciting for music tech hackers who are searching for a super-responsive feel for their builds.



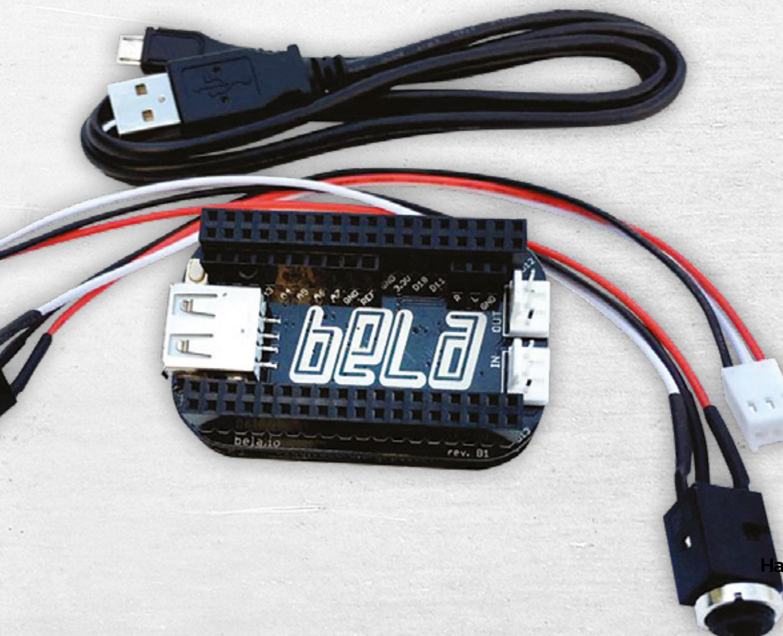
COMPATIBILITY

OK, so Bela is fast. But what really makes it exciting for me is how nicely it plays with not just C++ but a whole load of other music creation software platforms out there. If you're a Pure Data or SuperCollider user, you can just save your file onto the board, and it will run when the board is booted up. This means you can craft your noises using immensely powerful sound synthesis programs, then embed them into an instrument that you can play without needing to get your laptop involved. For someone experimenting with making their own instruments, being able to get a Pure Data file onto a fast, small embedded system is a game-changer!

GREAT DEVELOPMENT ENVIRONMENT

I'm a big fan of browser-based integrated development environments (IDEs), as opposed to downloading a new program for every board I want to play with. When I teach or run workshops, having to get every student to download and install something seriously eats into your teaching time, especially at educational institutions that don't have all the right permissions in place.

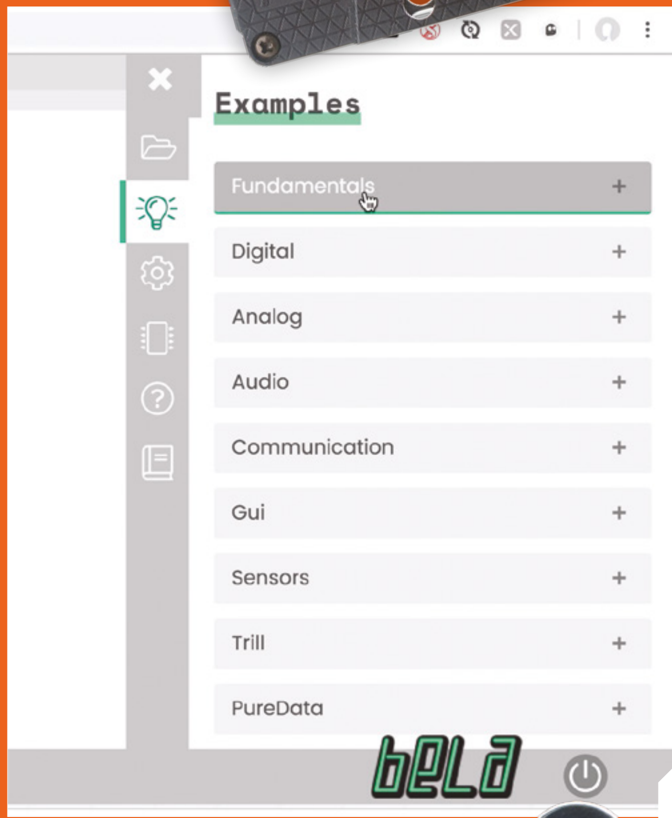
When you plug in your Bela, you point your browser to **bela.local**, and it will use the board as a kind of local server, showing you a neat IDE with tutorials, example code, pinout diagrams, and an extremely handy oscilloscope, which lets you look at multiple channels of data without disconnecting the board – great for debugging your sensors. There's also a great new ability to create Graphical User Interfaces (GUIs) that will allow for all sorts of cool data visualisations, including real-time graphing. →



AWESOME PROJECTS

Now you've had the whistle-stop tour of the technical capabilities of Bela and the BeagleBone, let's take a look at some of the seriously cool things people have done with it.

One of the simplest and most fun ways I've seen Bela's responsiveness demonstrated is the lightsaber project. Bela team members Robert Jack and Chris Heinrichs used a cardboard tube, an accelerometer, a piezo disk, a small speaker, a battery, and a Bela board to make a pair of excellent-sounding lightsabers for office duelling. The Pure Data audio patch the lightsabers are made with is a standard example in the Bela IDE, as is one of my other favourite simple projects, the pressure-sensitive rubber duckie. There is a detailed breakdown of the (simple) make and (not-so-simple) audio processing on the Bela blog at **hsmag.cc/caAQzl**



"THE PURE DATA AUDIO PATCH THE LIGHTSABERS ARE MADE WITH IS A STANDARD EXAMPLE IN THE BELA IDE"

The One-Handed Musical Instrument (OHMI) Trust is a charity that works on the design or adaptation of assistive musical instruments for people who are physically disabled. They run an annual competition for instrument design, and Jacob Harrison entered with a one-handed Bela bass. The instrument uses the Bela board and a lot of solenoids to adapt a bass guitar for one-handed playing by mechanising the fretting hand of a bass guitarist. You can see it in action and find a breakdown of the technology used on Jacob's blog.
hsmag.cc/7ZI0Bs

Axis is a kinetic sculpture by Astrid Bin, Daniel Gabana, and Liam Donovan that uses Bela to illustrate the irrational number Phi. Like the more well-known Pi, Phi's decimal fraction parts don't have a pattern or repeatable cycle. You can find Phi everywhere in nature, from the centre of a sunflower to the structure of entire galaxies. This hypnotising paper sculpture moves using 20 stepper motors, each controlled by their own ATtiny integrated circuit. Bela is the central control unit, cycling through choreographed movements that show Phi's chaotic nature in motion. See it for yourself on the Bela blog. **hsmag.cc/C0m0p2**

Aural Fabric is an interactive map of Greenwich by Alessia Milo. The project uses the MPR121, a Bela board, and electronic embroidery using conductive thread to trigger field recordings using capacitive touch. These field recordings were captured in Greenwich, then mapped into Aural Fabric's touchable soundscape. Explore the materials, technology, and sounds used in this project on the Aural Character blog. **hsmag.cc/A5gQnT** □

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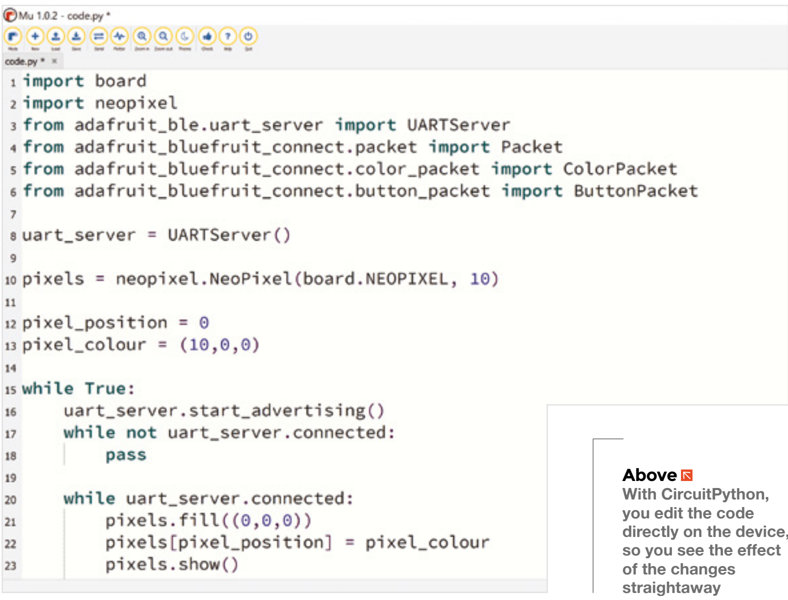
Improve your skills, learn something new, or just have fun tinkering – we hope you enjoy these hand-picked projects

CircuitPython and Bluetooth Low Energy

Link your phone to your microcontroller to send data and commands



Above With CircuitPython, you edit the code directly on the device, so you see the effect of the changes straightaway

Ben Everard

@ben_everard

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

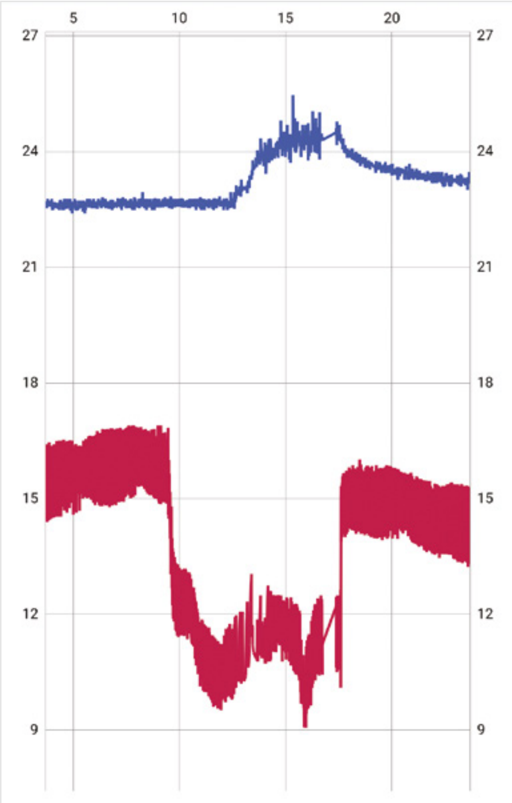
Bluetooth is in a bit of a funny position in the maker world. While theoretically it is really well placed to be a great addition to the maker toolkit, historically it's not been widely utilised because it's been hard to use. Part of the problem is the need to write two bits of software – one for the microcontroller, and one for whatever you're sending data to it with, whether that's a phone or computer. Where WiFi has enabled makers to do one side with a simple bit of HTML, Bluetooth has often needed a fully featured app. There's also a bit of confusion about names – Bluetooth and Bluetooth Low Energy (BLE) are different things, yet are both often lumped under the moniker 'Bluetooth'. We'll be using BLE. Things are getting a little easier thanks to a really easy-to-use set of modules in CircuitPython and the Adafruit Bluefruit app. We'll be using the Circuit Playground Bluefruit to take a look at how it works using this software setup. Be aware that this hardware and the version of CircuitPython that it needs (v5) are both currently in alpha, so you might hit glitches along the way, but this should stabilise soon.

Let's have a look at the simplest possible code, a 'Hello World' example:

```
import board
import neopixel
from adafruit_ble.uart_server import UARTServer
from time import sleep

uart_server = UARTServer()

while True:
    # Advertise when not connected.
    uart_server.start_advertising()
    while not uart_server.connected:
        pass

    while uart_server.connected:
        uart_server.write("hello world")
        sleep(5)
```

This creates a UART (aka serial port) server to run over Bluetooth. It puts it into an advertising state which lets other devices discover it and connect to it. Then, once connected, sends 'hello world' every five seconds. In order to view it, you need to install the Adafruit Bluefruit app (available for both Android and iOS).

When you first open the app, you will get a list of all of the Bluetooth devices in the area. In order to select just the ones that we can use, enter the Filter drop-down and check Must Have UART Service. You should then see a device called, something like, CircuitPYXXXX. Hit Connect and you should then see a range of options. Click UART and you should see the words 'Hello World' appearing every five seconds.



Left
You can send data to a graph on your phone using the plotter function in the Adafruit app

INTERACTIVITY

The UART is useful for sending debug data, but it's a bit clunky for general use. You could write a text-based interface for your build, but it's not 1980, and things have moved on a bit. Fortunately, the Bluefruit app also supports sending packets of data in standard formats. Let's take a look at how to use two of these formats: ColorPacket and ButtonPacket.

Our code creates a really simple demonstration on the Circuit Playground Bluefruit. It lights up one pixel at a time. You can use the colour picker to select a colour, and the control pad to move the lit LED around the ten available on the board.

We use the following code to loop through all the packets in the data stream:

```
packet = Packet.from_stream(uart_server)
```

Then, we select how to process this, depending on the type of packet it is, using statements like:

```
if isinstance(packet, ColorPacket):
```

We can get the relevant data from the packets by accessing the appropriate variable. For example: `packet.color` or `packet.button`.

The full code for this is as follows:

```
import board
import neopixel
from adafruit_ble.uart_server import UARTServer
from adafruit_bluefruit_connect.packet import
Packet
from adafruit_bluefruit_connect.color_packet import
ColorPacket
from adafruit_bluefruit_connect.button_packet
import ButtonPacket

uart_server = UARTServer()

pixels = neopixel.NeoPixel(board.NEOPIXEL, 10)

pixel_position = 0
pixel_colour = (10,0,0)

while True:
    uart_server.start_advertising()
    while not uart_server.connected:
        pass

    while uart_server.connected:
        pixels.fill((0,0,0))
        pixels[pixel_position] = pixel_colour
        pixels.show()

        packet = Packet.from_stream(uart_server)
        if isinstance(packet, ColorPacket):
            print(packet.color)
            pixel_colour = packet.color
        if isinstance(packet, ButtonPacket):
            if packet.pressed:
                print(packet.button)
                if packet.button == '7':
                    pixel_position = pixel_position
- 1
                    if pixel_position < 0:
                        pixel_position = 9
                if packet.button == '8':
                    pixel_position = pixel_position
+ 1
                    if pixel_position > 9:
                        pixel_position = 0
```

You can send data to your device using the Bluefruit app by selecting Controller, then Control Pad or Color Picker.

There are a few other types of packet that we haven't used here. These can be used in the exact same way as Color and Button Packets, and have variables named x, y, and z that you can access.

Bluetooth on CircuitPython really is this easy. This gives you plenty of options for controlling your projects remotely, whether that's driving a rover around using your phone as a controller, or triggering events.

PLOTTER

As well as sending text to the app, you can send numbers, and there is a plotter function in the app to show them in a live-updating chart. Just send text containing the numbers using the same Write function we have used in our examples. If you want to display more than one number, separate them with a comma.

Note, however, that there is no way of saving the data sent, so if you need to keep a record of it, you will need to store it elsewhere. There is an example showing this at the following link: **hsmag.cc/R6bWfb**.

Designing parts for CNC milling

Let's explore the open-source software FreeCAD for creating a simple 3D model and some toolpaths for CNC routing

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!

YOU'LL NEED

- Laptop with FreeCAD installed

FreeCAD is a popular open-source tool for designing things in three dimensions, and we're going to look at how to use it to create designs that we can mill using a CNC machine. This way, we can create parts out of wood or metal potentially much larger and stronger than we can with other automatic fabrication methods such as 3D printing or laser cutting.

To begin, fire up FreeCAD and you will be met with a page called 'Start Workbench'. From here, click Create New in the Documents tab, creating a new tab on the right-hand side with an area in which our models will appear. On the left-hand side, we can see the beginnings of a file tree view in the Model tab, with 'Unnamed' appearing under Application. A primary concept in FreeCAD is the idea of multiple workbenches, with each one having its own collection of tools – much like physical workbenches in a hackspace. Using the drop-down workbench menu that currently says 'Start', we are going to switch to the 'Part' workbench (**Figure 2**).

In the Part workbench, we can create primitive 3D objects like cubes and cylinders. We can also perform Boolean operations on these objects, such as cutting one shape out of another or merging two objects into one. For this project, we are going to design a simple disc with a hole and a pocket cut into it – not the most amazing project, but we can learn a lot along the way.

First, select the yellow icon that looks like a cylinder; it should be in a row of tool icons with a yellow cube, cone, sphere, and more. Clicking the cylinder icon makes a cylinder appear on the right-hand side. On the left-hand side, within the

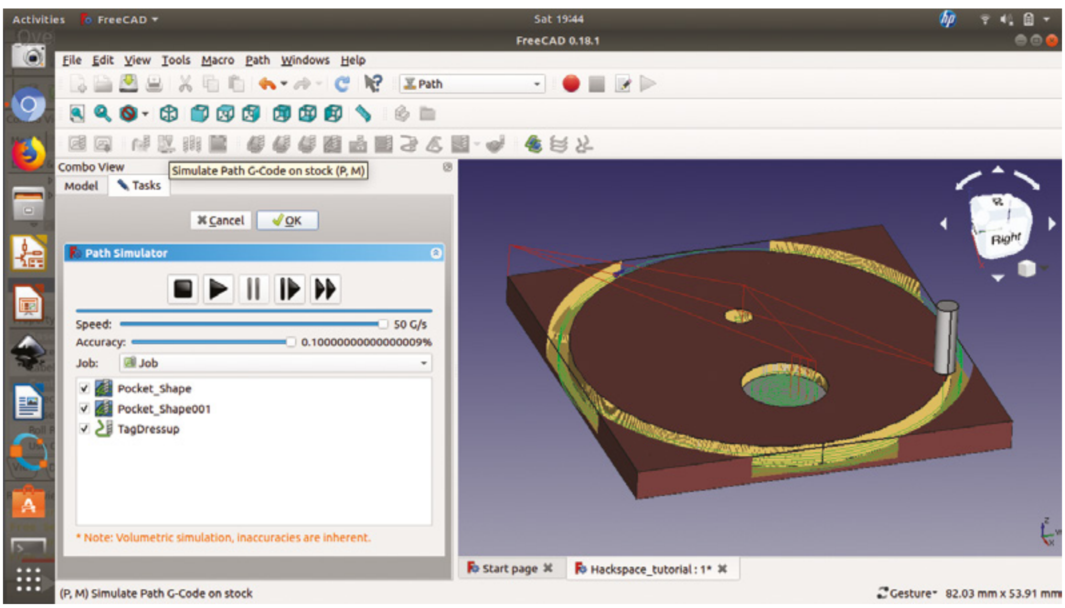


Figure 1 The complete designed part we are aiming for with the toolpaths and a simulation of the cutting operations performed in FreeCAD

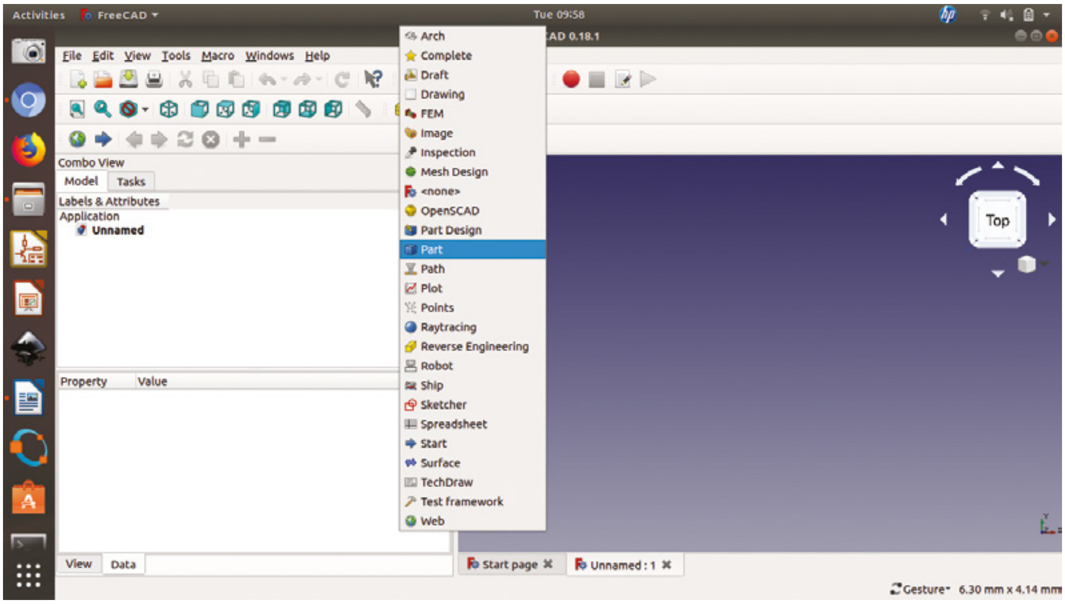


Figure 2 Using the drop-down menu to switch between different workbenches to use different tools and approaches

Model tab file tree view, you should now see Cylinder listed under Unnamed. You should see a dialog box, into which you can change some details relating to the cylinder object we just created (**Figure 3**).

Having made a cylinder, let's change its size. We are going to eventually CNC-rout our flat disc from some 3.13 mm plywood – so let's make this cylinder 3.13 mm tall. Change this dimension in the dialog box on the lower left, as seen in **Figure 3**. Then change the radius to 26 mm.

We are now going to repeat the above process to make another cylinder; this should appear in the file tree as 'cylinder001' and should be below our original 'cylinder'. Change the size of this cylinder to a radius of 6 mm and a height of 2 mm. It will now appear to have disappeared, as it is underneath our original cylinder. In the dialog box, expand the 'placement' drop-down and then the 'position' drop-down, and let's change the position of this cylinder. Change the z coordinate to 1.3 mm. This raises the cylinder up 1.3 mm and sets the top of the cylinder flush with the top face of our original larger disc. Set the x axis position to 10 mm.

The next operation we are going to do is to subtract the second smaller cylinder out of our first to leave a 2 mm deep pocket. To do this, hold the **CTRL** key down whilst selecting both the cylinders in the file tree. Next, find the 'Make a cut of two shapes' tool (**Figure 4**). Click the button, and the smaller cylinder should be cut out of the larger disc.

If at this point the larger disc disappears, press **CTRL+Z** to undo and reselect the two cylinders, but select them in the reverse order from what you did the first time and try again!

We repeated the above operation with a 2 mm radius, 10 mm tall cylinder to create the small hole through the piece, and we positioned this hole at -9 mm in the x axis.

> "We are going to design a simple disc **with a hole and a pocket cut into it**"

WALKING THE PATH

Toolpaths are the path that a cutting tool follows. This, together with some information about the size and shape of the cutting tool and the speed and feed rates the tool is travelling at, will all be combined into a G-code file which we can send to a CNC router. To begin this process in FreeCAD, we need to switch to the Path workbench. Next, we need to select →

QUICK TIP

CAD stands for Computer Aided Design, and CAM stands for Computer Aided Manufacturing.

NAVIGATION

In FreeCAD, you can change the navigation style between various options to make the mouse/trackpad button combinations respond in different ways when navigating around a part or model. In the window with the parts and models, right-click and you will see the different options. If you see an option from some other software you are familiar with (Maya, Blender, and others), then that may be a good choice for you. We settled on the 'Gesture' option. In the Gesture navigation style, holding down the left mouse button allows a model or part to be rotated with the trackpad; a held right button allows the model to be moved around the stage, and the centre mouse button plus movement on the trackpad enables zoom in and out. You can also manipulate the view of the model using the block and clicking arrows in the upper right-hand corner – or on some workbenches, you have icon buttons that set the view to different planes (these look like small blue cubes with a different face set as solid blue).

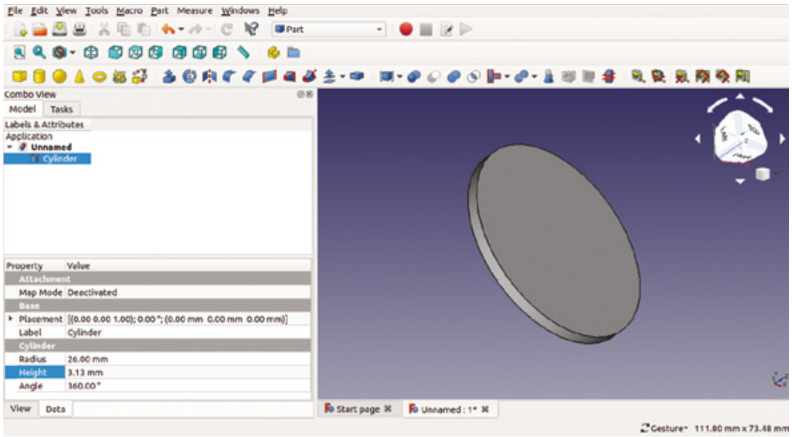


Figure 3 Forming a flat disc using the cylinder primitive tool

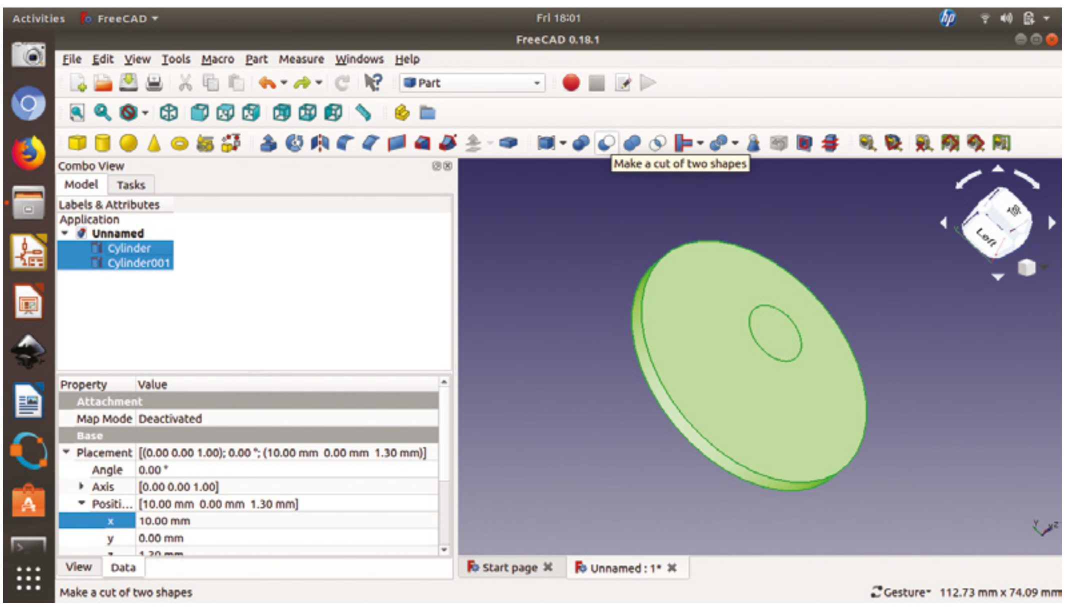
everything we have created (simply highlight the cut001 in the file tree view) and click the 'Create a path job object' tool icon. This button should be the only new icon that is available and not greyed out, appearing as a drill bit on the right-hand side of some green lines.

FreeCAD now will appear to have surrounded the disc we modelled with some lines, and a dialog box appears. FreeCAD has actually made a copy of the object, and has made the original object not visible. To toggle visibility of items in FreeCAD, you simply hover over them in the file tree view and press the **SPACE** bar. It's important from now on that the original model is invisible, and that we work on the 'Job' model.

These lines, the bounding box (**Figure 5**), represent the stock material we are going to machine the disc out of. As we are going to use 3.13 mm plywood that is the correct thickness, we don't need any material above the surface of the disc. Therefore, we will adjust the z axis dimension of the bounding box in the 'Setup' dialog box to reduce the stock dimension to zero by changing the 1.00 mm on the second z axis column to 0.00 mm. Clicking 'OK', we should then be able to see that the top line of the bounding box is level with the top of our model. We are also going to change where the zero or datum is on our model. Double-click 'Job' in the file tree and then carefully select the node point at the left-hand corner of the bounding box on the level of the top of the bounding box. Having selected the node, click the 'Set origin' button. The red, green, and blue datum arrows should move to this corner now. This can be seen as the origin of the red tool travel lines in **Figure 1**.

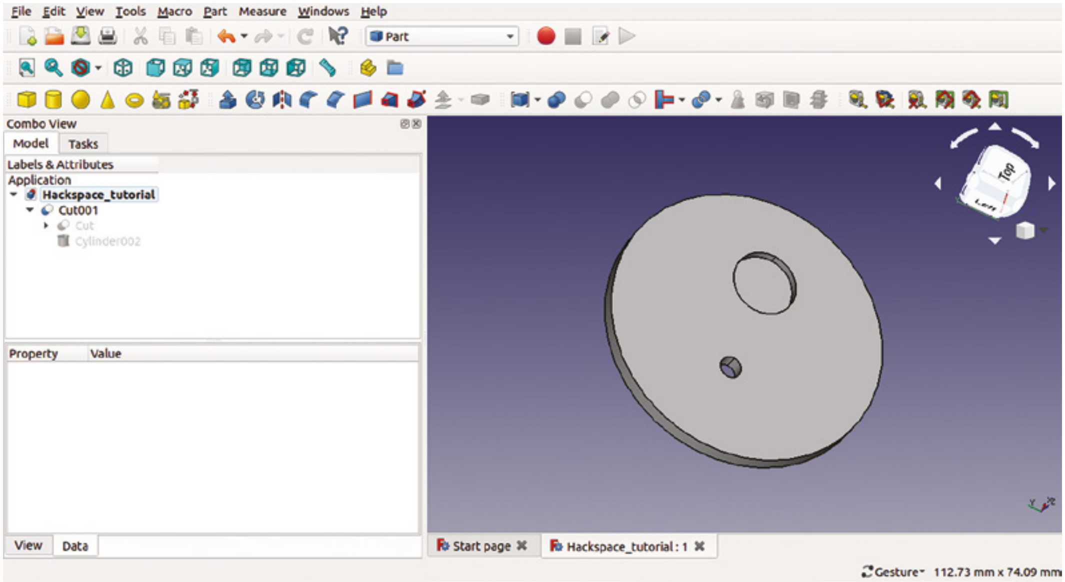
Next, we are going to create a new tool to use, and create a tool controller. To start this, click the icon that looks like three drill bits called 'Tool Manager'. In the window that appears, click 'New tool', and then, in the tool editor window that appears, we are going to specify the dimensions of a cutting bit. For all our CNC operations on this job, we will use the same tool – a 3 mm diameter, two-flute end mill. Give your tool a name such as '3 mm end mill' and set the 'H' to 15 mm (this is the available height of cutting surface on the tool, not the length of the entire bit). Click 'OK' to return to the 'Tool Library' window. Before closing this window, select the tool you just made and click the 'Create Tool Controller(s)' button (**Figure 6**). In the file tree, you

Figure 4 Using the Boolean tools to combine and subtract primitive shapes from one another allows more complex parts to be designed



QUICK TIP

There are hundreds of tutorials for the different workbenches online; we recommend looking at the 'Sketcher' workbench as a next step to creating more complex shapes after this tutorial.



Left Here is our model, complete with the pocket and the through-hole; we are now ready to add toolpaths to enable this to be CNC-routed

should now have a tool controller that has the name of the tool you just created. Double-click on this and bring up a dialog box. In this Tool Control editor, we can set the feeds and speeds of this tool. We set ours to a conservative horizontal feed of 350 mm/min and a vertical feed of 100 mm/min.

The first toolpath we will generate is the path the tool takes to cut out the pocket for the small cylinder we placed, cut part-way through the larger disc. Select the bottom face of that hole and then click the 'Create a path pocket object from a face or faces' button. In the 'Pocket Shapes' dialog box, we then set the depth of cut on the 'Depths' tab – so we are starting from 0.00 mm and cutting down to -2.00 mm. And we are conservatively again going to step down in increments of 0.5 mm, so it'll take four passes to cut this pocket. We also need to check the height clearances; on the Height tab, we set the safe height

"The first toolpath we will generate is the path the tool **takes to cut out the pocket for the small cylinder**"

to 3.00 mm and the clearance height to 5.00 mm. Finally, on the 'Operation' tab, we set the cut mode to 'conventional', the pattern to 'spiral', and the step over percentage (the amount the tool moves outwards on the spiral after each turn as a →

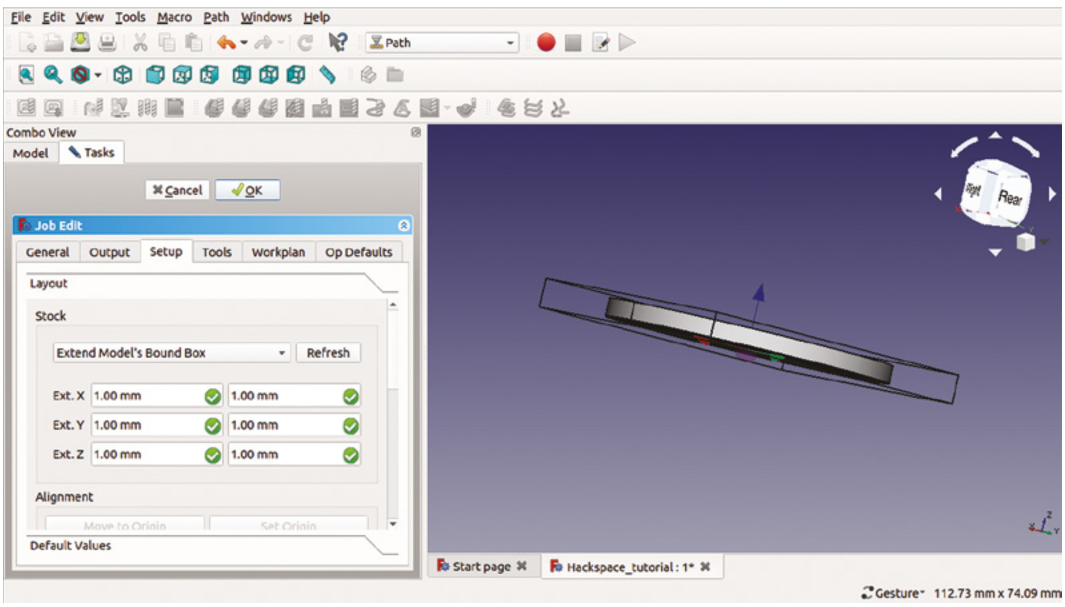


Figure 5 The path job object has been created, and we are ready to adjust the lines that represent the stock material

QUICK TIP

Throughout this tutorial we have used the correct names of icons, which are the names that appear if you hover over them. If you are having trouble finding the right icon, hover over some until you find the one that matches!

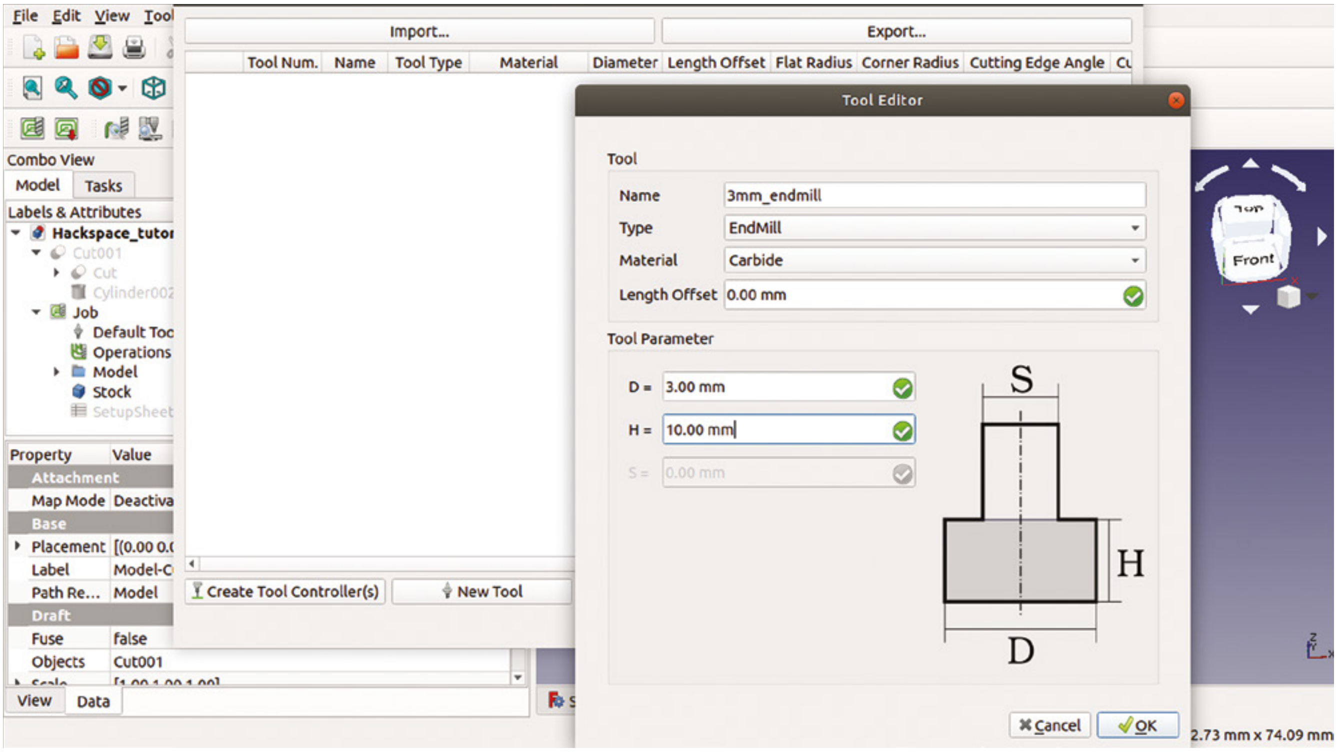


Figure 6 Adding a new tool using the Tool Manager dialog

percentage of the tool diameter) to 40%. Click the 'Apply' button and you should see your first toolpath appear on the model (**Figure 7**). Repeat the above section, but create a toolpath using the inside face of the through-hole. Follow the same process, but set the tool to a depth all the way through the disc.

We need to cut out the shape of the overall disc from the stock. To do this, we are going to select the whole model and select a 'Profile based on face or faces' operation instead of the pocket cut operation we used earlier. Select this and set the depths and heights. You will notice under the 'Operation' tab that we have the option to set the tool to the inside or the outside of the path – set this to outside and the direction to CW. Click 'Apply'. If we cut this path in its current form, the workpiece would become loose as the machine cuts it out, and the work might be rapidly ejected! Adding 'tags' to the toolpath means that the machine leaves small tabs holding the part to the stock, and then we remove the part from the stock by hand. Make sure

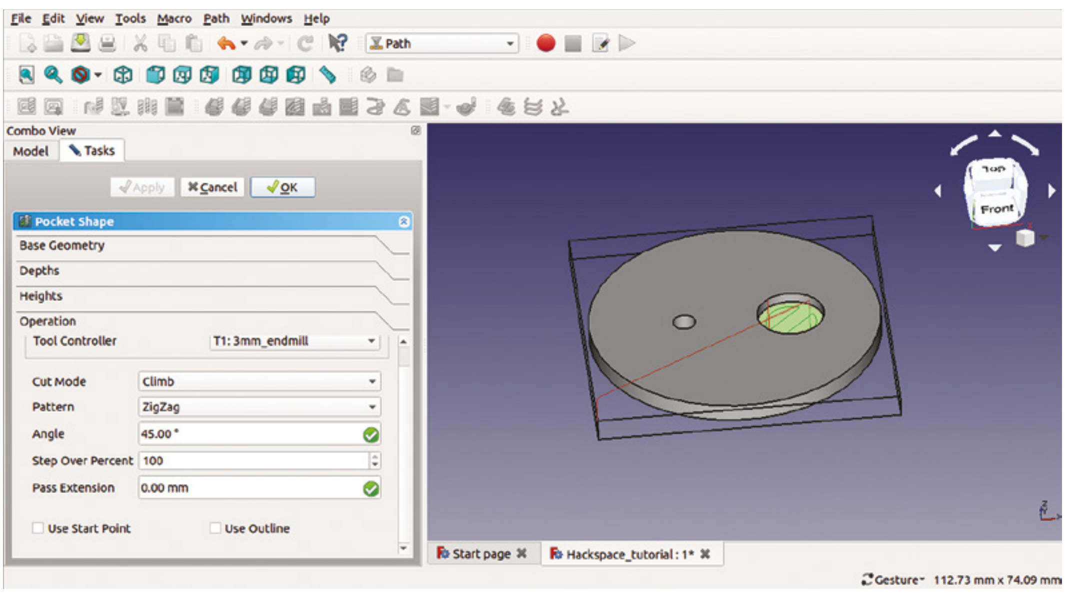
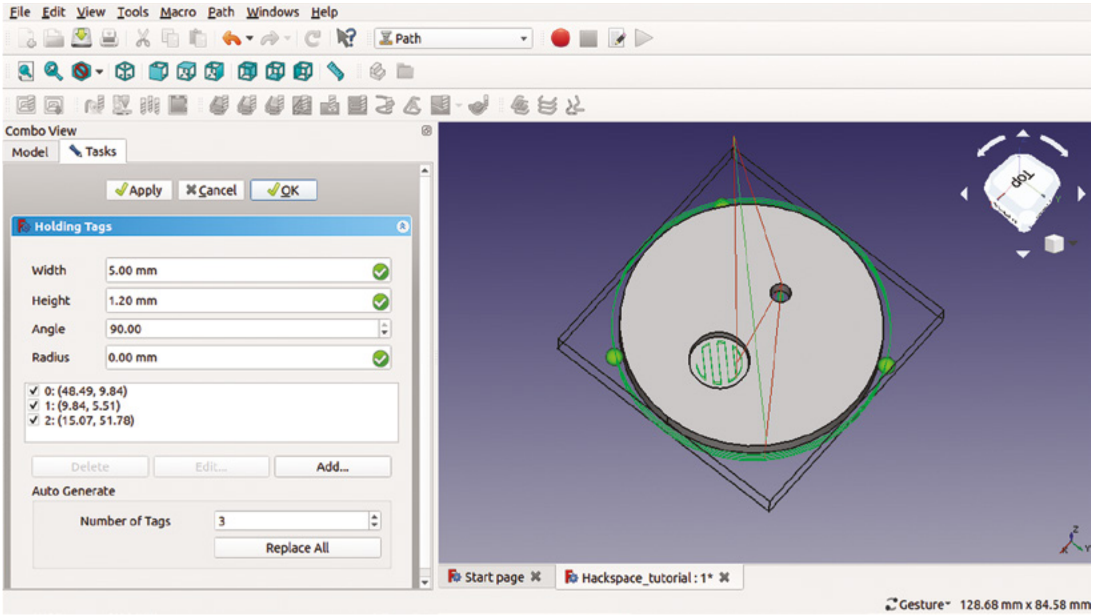


Figure 7 Creating the first toolpath. We tried a zigzag toolpath for this operation before settling on a spiral path and reducing the stepover

QUICK TIP

For simplicity, we're using the same tool to do everything in this tutorial. However, you might want to use a different tool and different operations. For example, we could drill the through-hole using a regular drill bit tool and a drilling operation.



QUICK TIP

If your units don't appear in mm/min, click Edit > Preferences and then, under the 'Units' tab, select 'Metric small parts and CNC' from the drop-down 'User System' menu.

the profile path we just made is selected in the file tree view, and then click Path > Path Dressup > Tag Dressup from the main toolbar. In the resulting dialog box, we set the number of tags to 3, the width to 5.00 mm, and the height to 1.2 mm. Clicking 'Apply' adds the tags – if you zoom in, you can see the tool has moved around the tags, leaving material.

Finally, we need to export our toolpaths as G-code, ready to be used with our CNC router. Double-click the 'Job' entry in the File System view. In the dialog box, click the Output tab to see various options (**Figure 8**). Different CNC machines use slightly different forms of G-code, and some have post-processors to ensure the code is exported in the correct format. FreeCAD has numerous built in, including the one we want to use: 'grbl', because the CNC router we'll be using is controlled using the open-source Grbl system. We selected 'grbl' and added a location and a file name for our G-code file. Grbl likes files with the suffix .nc, so we added this. Click 'OK' on the dialog box and then use the 'Post process the selected job' option (next to the 'Create a path job object' button we used earlier) and save the processed G-code file.

Congratulations on making your first model and first G-code file to cut the part on a CNC router. Next month, we will use this file as we look at the basics of getting started on a CNC router. □

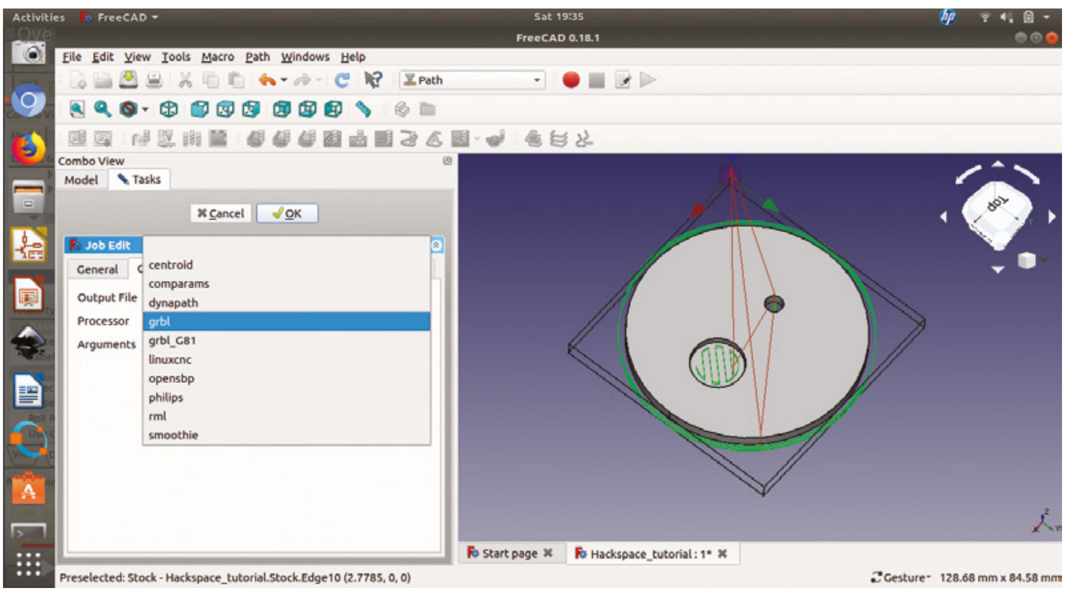
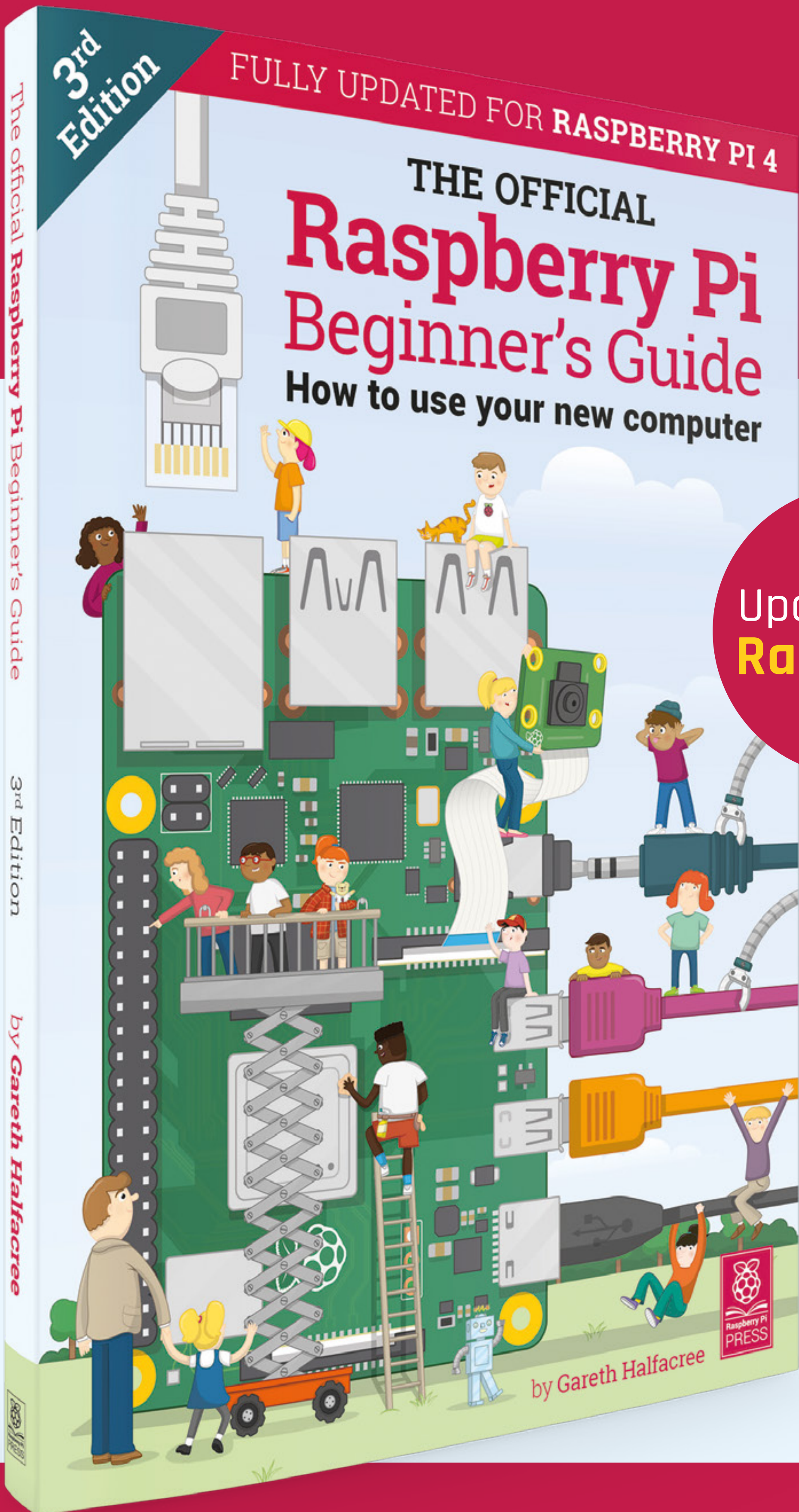


Figure 8
Selecting the post-processor that will create the correct G-code flavour for the CNC router we wish to use to cut our part

QUICK TIP

When you have all your path operations set up, click the 'Simulate Path G-code on Stock' button to see a simulation of the tool performing the CNC routing. A useful check that everything is OK, as seen in **Figure 1**.



Fully Updated for **Raspberry Pi 4**

Lights, buttons, music!

Making beautiful, weird sounds with a NeoTrellis

Ben Everard

@ben_everard

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

Above This instrument looks brilliantly cyberpunk when in use

The Adafruit NeoTrellis brings together some great elements for an electronic musical instrument. It combines an interface that's responsive, tactile, and flexible (both literally and metaphorically) with a microcontroller that's powerful enough for some interesting audio effects. Let's take a look at what this means by building a simple instrument. It combines a step sequencer, a drum machine, and an effects unit into one portable device.

We'll be bringing together two Arduino libraries to create this – the NeoTrellis library from Adafruit, which brings in what's needed to control the hardware, and the Audio library from Teensy creator Paul Stoffregen, which will do the audio synthesis and manipulation.

SOUND IN SEQUENCE

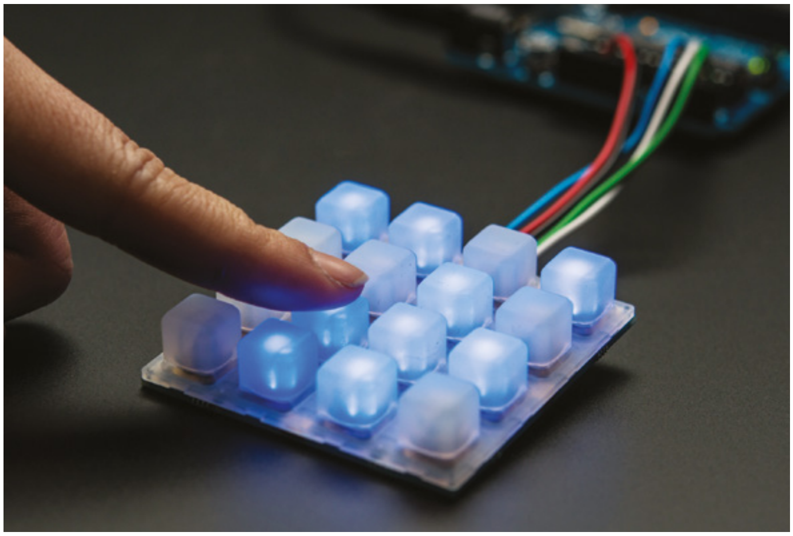
A step sequencer is a device that cycles through a series of different points. At each point, it plays a predefined sound. The NeoTrellis M4 has a grid of four rows of eight buttons. Each button contains an RGB LED that can be used to light that button up in any colour. We'll use this to create a 'toggle' effect – press a button once and it lights up; press it a second time and it turns off.

With the eight by four layout, it makes sense to step through sequences of either four or eight notes. We're going to use four notes, so each row of buttons can be used to define the sound that's played on that beat. We'll split the row into two sections. The leftmost three buttons each control a 'drum' sound (that doesn't sound too much like a drum, but more on that later). The rightmost four buttons define different effects that you can apply to these sounds. That leaves us with one free column – the fourth from the left – which we'll use for lights (without the buttons doing anything). This will indicate which beat is currently playing.

If you want to skip right ahead and just install the software, you can grab it from: **hsmag.cc/ykFEND**. The interesting part about this project isn't the synth

HARDWARE

The Audio library is tied closely with the hardware, and it only runs well on two platforms: the NeoTrellis M4 and the Teensy line of microcontrollers. If your project doesn't need the buttons of the NeoTrellis, we'd strongly recommend using one of the Teensies. We took a look at the Teensy 4.0 in issue 20. It's amazingly fast, which lets you cram in even more audio and effects. As you may have guessed by the name, it's tiny enough to fit into almost any project.



itself, but how it's built. You can build your own instrument using the same technique, but customised for the type of music you like to play.

As is so common, we didn't start our code with a blank page, but with one of the example scripts from Adafruit that implements the toggle function – press a button and it lights up a random colour. Press it again and it turns off the light. You can get the code from: **hsmag.cc/tTomu8**.

Since we don't need the colours to show the particular value, we kept the random colours to make it a little more delightful.

We won't go through the complete code, but we modified the main loop to do this, but not allow the user to turn the fourth column on or off. It's as follows:

```
  while (trellis.available()){
    keypadEvent e = trellis.read();

    if (e.bit.EVENT == KEY_JUST_PRESSED) {
      int key = e.bit.KEY;
      if(key != 3 and key != 11 and key != 19 and
key != 27) { // ignore fourth col
        Serial.print(key); Serial.println("
pressed");
        lit_keys[key] = !lit_keys[key];
        if (lit_keys[key]) {
          trellis.setPixelColor(key,
Wheel(random(255)));
        } else {
          trellis.setPixelColor(key, 0);
        }
      }
    }
  }
```

This almost gives us our complete interface. Each row of the keyboard on the eight by four keypad represents one beat (our synth will continuously loop a four-beat sequence). The columns split up the interface into three sections. The leftmost three columns each define a sound that can either be played or not. The fourth column lights up one row in turn to show which beat is currently playing, and the rightmost four columns are effects that we can apply to the sound.

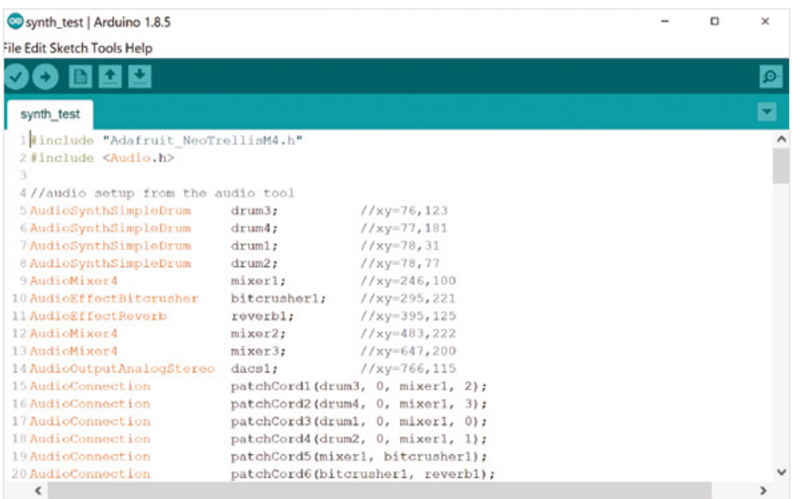
We only need to create the audio side of things. The Audio library is inspired by modular synths, where you have discrete devices that you can connect together using patch cables. There's a web editor for creating these which you'll find at **hsmag.cc/6ykYDw**. You can drag and drop different bits into your device and then press Export to get the Arduino code to copy and paste into your Arduino code. We don't need all the `include` statements, just the bits under `//GUITool`…

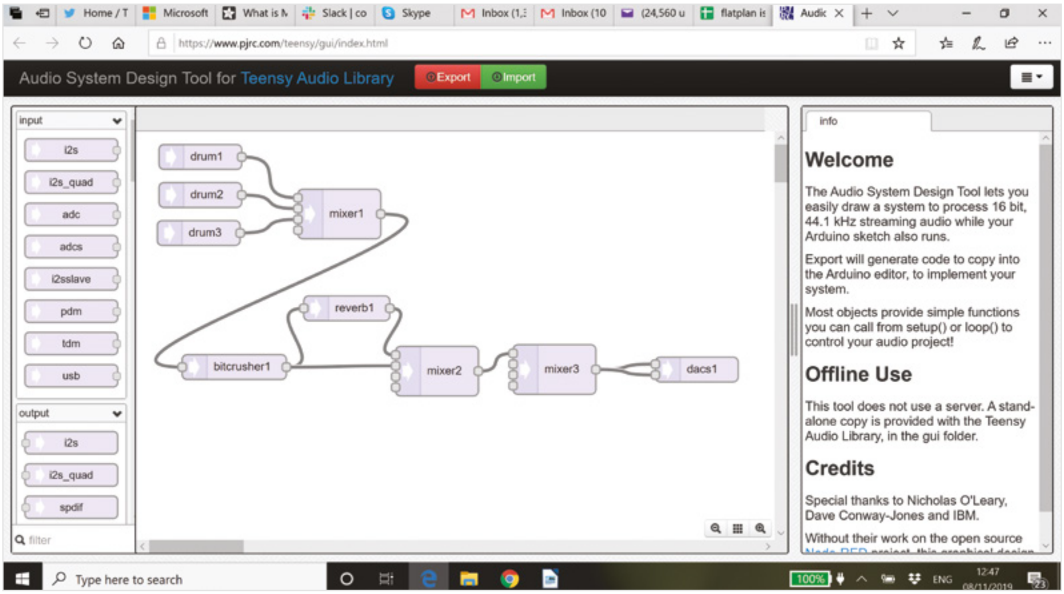
Take a look at **Figure 1** (overleaf) for details of how we set this up (you can also use the Import function to take the relevant bits of code and bring them into the graphical editor).

There are three drums, named drum1, drum2, and drum3. These don't really create drum-like sounds →

Above Want a bigger or smaller instrument? Adafruit sells the keypads separately so you can build up larger grids and connect them to whatever microcontroller you like

Below Just copy and paste the code from the Audio library GUI into an Arduino sketch, and you're halfway there!





(well, they can, but it depends on how you program them). These will be tied to the first three columns of our interface. The four effects columns will be tied to:

Bitcrusher bit rate

This reduces the number of bits per sample in the audio stream from 16 to 2. When on, this creates a very distorted, square-ish wave sound.

Bitcrusher sample rate

This reduces the number of samples in the audio stream from 44,100 per second (CD quality) to 8000. This is too low to accurately capture all the audio frequencies, so it will introduce some anomalies.

Reverb

This expands the sound as though it were reflecting off many objects and echoing around.

Amplifier

The most obvious of the effects, this makes the sound louder.

The effects require slightly different ways of connecting them.

The drum sounds all feed into a mixer, and the output of this goes into a bitcrusher effect which can be used to dramatically reduce the bit rate of the audio signal, giving it a distorted effect.

Importantly, the bitcrusher effect can be turned off. In effect, we just set it to use the full sample rate or bit rate. At this point, the block has no impact on the audio stream, which passes through unaltered.

Reverb is slightly different because it always produces a reverb (though we can change the amount of reverb). In order to turn it off, we have to have a way of bypassing the effect completely (which, in this case, means a parallel connection to a mixer and we can use this mixer to select which of the two inputs to use). We could use this mixer (mixer2) to control the amplification effect as well, but we put in a dedicated mixer just for this to keep the code a bit cleaner (and since we have enough memory and CPU power to handle it, why not use it to keep the code a bit easier to read?).

That's the synth set up in the web app, now let's look at how to bring this into the Arduino editor.

If you press Export, you'll see a bunch of Arduino code. It'll include some libraries; then there'll be some statements like the following, which create the objects:

```
AudioSynthSimpleDrum      drum3;
```

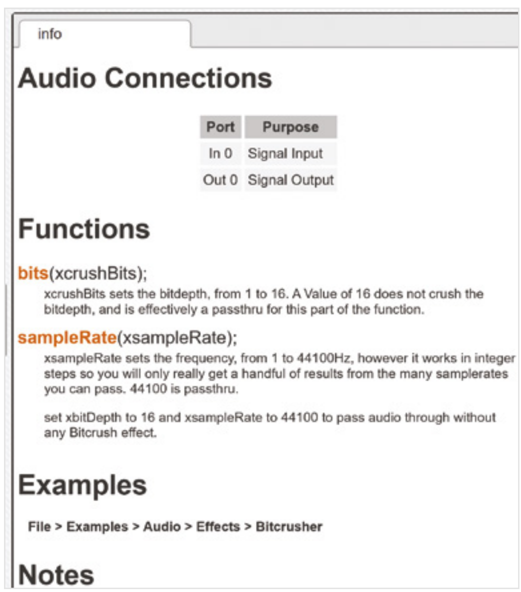


Figure 1 This is our effects setup, but you can set it up however you like

Right If you're unsure how to use any object in the GUI, click on it and you should see the necessary details in the info box

And some, like the following, which define how everything is joined together:

```
AudioConnection          patchCord7(reverb1, 0,
mixer2, 0);
```

You don't need to use the GUI editor at all – if you'd rather, you can write these by hand, but we find it easier to see what's going on with the GUI tool.

The GUI tool can only define the connections between the different parts of the audio synthesizer; we'll need to dive into the code to actually make it do what we want.

Still in the first part of the code, we have to define what buttons in the keypad do what, so we create a series of arrays such as:

```
int drum1keys[] = {0,8,16,24};
```

These arrays are set up so that the **beatcounter** variable can be used as an index to each array to look up the buttons that are used in that beat.

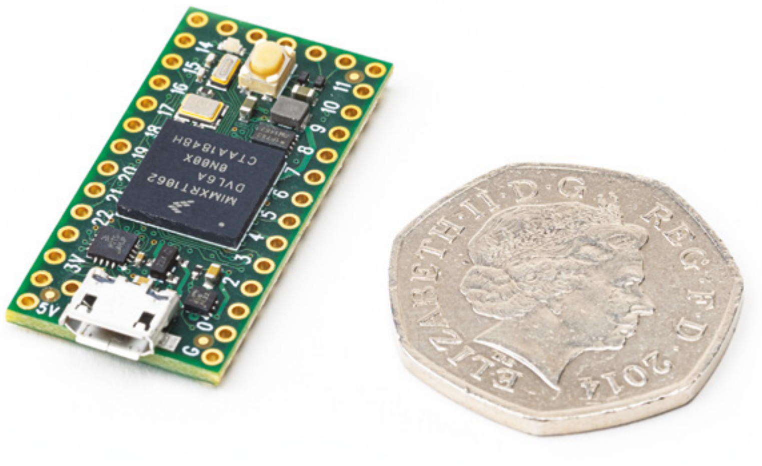
Then, in the **setup** function, we need to initialise all the audio objects. This is done with:

```
  bitcrusher1.bits(16);
  bitcrusher1.sampleRate(44100);
  reverb1.reverbTime(0);
  mixer2.gain(0,0);
  mixer2.gain(1,1);
  mixer3.gain(0,1);
  drum1.frequency(40);
  drum2.frequency(80);
  drum3.frequency(160);
```

The different audio objects all have different methods, which can be a bit confusing, but fortunately they're all documented in the web interface. If you click on an object, details of that type appear in the right-hand panel, including the functions it has and the examples that demonstrate it.

That's all our bits and pieces set up and ready to use. The final part is to link it all to both the beat and the button presses. The full code is at **hsmag.cc/ykFEND**, but here's a stripped-down version of the loop showing one of the drum sounds and the bitcrusher effect.

```
void loop() {
  // put your main code here, to run repeatedly:
  trellis.tick();

  //has a beat taken place
  if (millis() > lastbeat + timetobeat) {
    lastbeat = millis();
    beatcounter++;
    if (beatcounter > 3) { beatcounter = 0; }

    //light up the beat keys
    for (int i = 0; i<4; i++) {
      trellis.setPixelColor(beatkeys[i], 0);
    }
    trellis.setPixelColor(beatkeys[beatcounter],
  trellis.Color(50, 50, 50));

    //drums
    if (lit_keys[drum1keys[beatcounter]]) {
      drum1.noteOn();
    }
     //bitcrusher
    if(lit_keys[bitcrushbitkeys[beatcounter]]) {
      bitcrusher1.bits(2);
    }
    else {
      bitcrusher1.bits(16);
    }
}
```



Above If you need more power to run your effects, you could consider the Teensy 4.0 – the most powerful microcontroller that can run the Audio library

That's all there is for our simple synthesizer. The excellent Audio library gives us a really flexible base to build off, and we've only really scratched the surface of it here. It's got far more options with regards to both synthesis and effects; it can take audio from external sources and send it on down the pipeline (via I^2S). It's one of those brilliant libraries that's both easy to pick up and powerful enough for some serious uses. Our only warning with it is that it can become very addictive!

GOING FURTHER

If we have whetted your appetite for more, Paul Stoffregen gave a great walkthrough of the features of the Audio library at the Hackaday SuperConference in 2015. A video of this, and all the associated materials, are on the Hackaday website at **hsmag.cc/jTYHH4**. This is a great starting point for further exploration of the library and audio on microcontrollers.

TUTORIAL

How do your skills with a ruler measure up?

There's more to measuring for makers than 'measure twice, cut once'

Gareth Branwyn

@garethb2

Gareth has been a lifelong practitioner (and chronicler) of DIY tech, media, and culture. He is the author of ten books, including *Tips and Tales from the Workshop*, and is a former editor for Boing Boing, Wired, and Make:.

Above The knurled knob is a scribe handily placed to be there when you need it

The success of a project can greatly depend on the accuracy with which you measure and mark your materials. Here are a few tricks of the trade that can increase your chances of making your marks where and how you want them.

Drawing straight lines on the fly I learned this indispensable trick from maker extraordinaire, Jimmy DiResta. You can draw a fairly accurate straight line along the edge of a workpiece by holding a pencil between your thumb and index fingers as normal, and with your other fingers, press your hand firmly against the edge of the workpiece. Now, holding your hand as steady as you can, draw it down the length of the workpiece to scribe your line. For lines farther in than the width of your hand, hold a ruler or tape measure in your hand, press your pencil firmly against the end of the ruler, and draw your hand and ruler along the length of the board to mark your line. It takes a little practice, but it's a great skill to have.

Equally dividing workpiece without much maths To easily divide a workpiece into equal parts, do the following. Let's say you have a 7″ wide piece of cardboard that you wish to divide into four equal strips. Place your ruler so that the zero mark is along one edge of the workpiece. Now, move the ruler down along the other edge of the cardboard until you reach a number that is easily divisible by four. (In our case, 8″.) Next, simply mark the 2″, 4″, and 6″ ticks on the ruler. Do the same farther down on your workpiece and connect the lines. You now have the piece divided into four equal strips.

Finding the rough centre of a workpiece If you have a strip or rod workpiece that you want to find the rough centre of, hold the piece starting with your hands on both ends and then move them toward the centre. When you find the balancing point in the middle, that will be your rough centre. This is another DiResta trick. To see this, and for more great measuring and marking tips from Jimmy, see his *DiResta Jimmy Tips 4* on YouTube.

YOU rule! You can use your hand, arms, and feet as measuring devices. Measure and memorise things like the two segments of your index finger, the height and width of your hand, the length of your foot, your forearm, etc. This can come in handy when you need to measure something and have no measuring device available.

THANKS

Thanks to the following makers for input on this article: Jimmy DiResta, Michael Pechner, Eric Kaplan, Michael Colombo, Mary Krantz, Bob Knetzger, Alan Turner, Tyler Winegarner, Kris DeGraeve, Joe Schepps

> Did you also know that the slit on the tang is designed **to grab a nail head for one-person measuring?**

Tape measures move for a reason The tang (end hook) on a tape measure appears to have a sloppy rivet that moves back and forth. This is on purpose. It has exactly ¼" of travel (the thickness of the tang) so that you get an accurate measurement when you are hooking the tang over an edge or butting the end of the hook against a surface. Did you also know that the slit on the tang is designed to grab a nail head for one-person measuring?

Storey sticks If you do a lot of repetitive measuring, it is a smart idea to create what's called a storey stick or storey pole. On a narrow length of board, you mark whatever custom measurements you need to remember. The name comes from house-building, and the use of such a marking stick that is one storey high.

The right marking tool for the job When marking, use the tool that's appropriate to your materials, tolerances, and working conditions: thin mechanical pencil for finishing work, carpenter's pencil for framing, masonry, etc., where tolerances are low (and for visibility), and grease pencil or marker for indelible marks, especially outdoors.

Razor-sharp marking If you want to make a super-precise mark, don't use a pencil, or even a scribing tool, use a razor knife. If you need to 'light up' the line you made so that you can see it better, rub some sawdust over it.

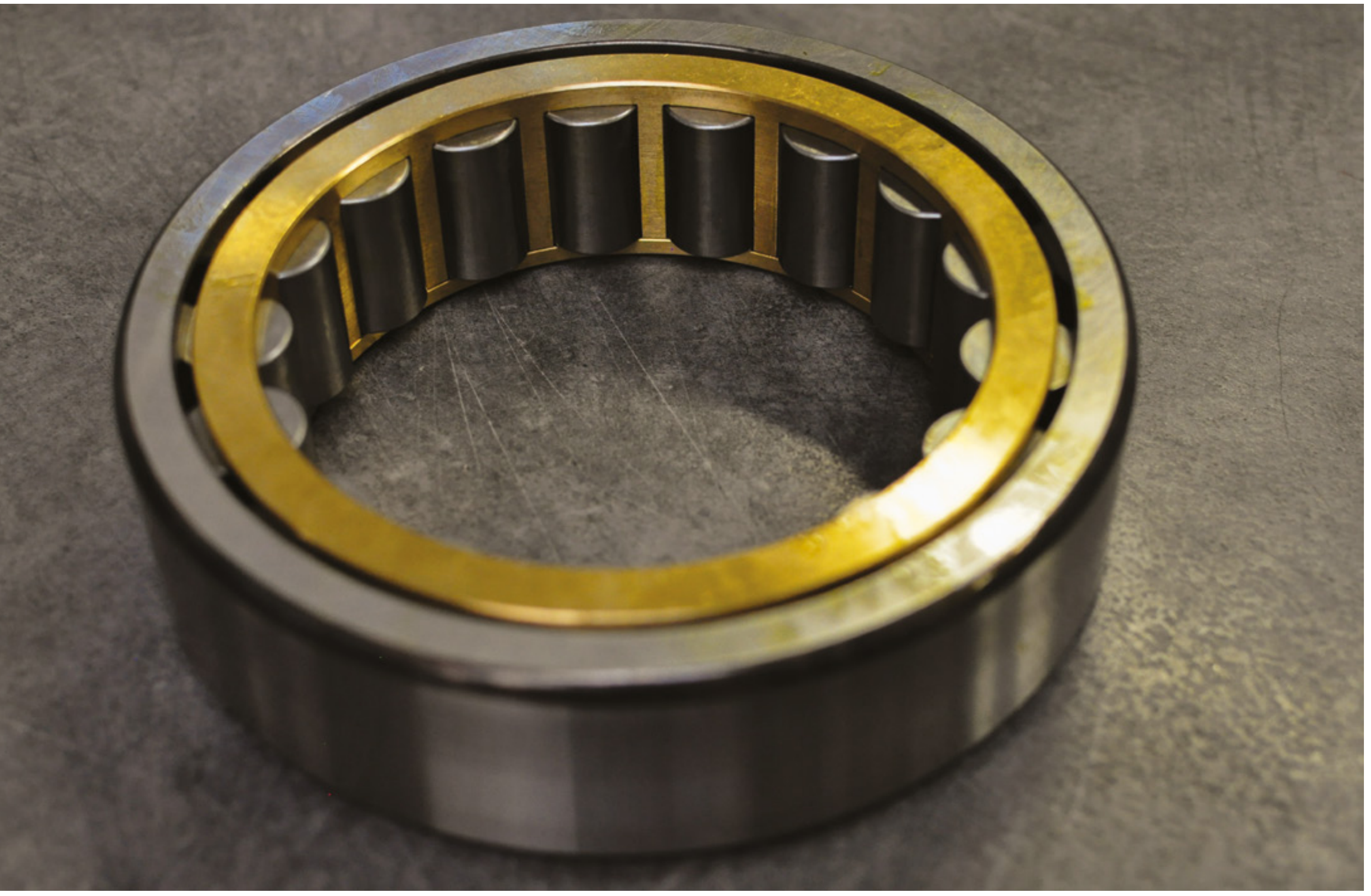
A hidden scribing tool That knurled knob that has likely gone unnoticed on your combination square (it did for me until just a few years ago) is actually a built-in scribing tool. Unscrew and enjoy.

The squiggly line of untrue When you have material stock with edges that you are not certain are 'true', mark them on both sides with a squiggly line (or other consistent marks) to remind you not to trust those edges. □

Left Quickly mark straight lines with your hand

Above Keep the tape measure as perpendicular as possible

Below Angle your ruler to create equal marks on inconveniently sized material



Finding your bearings

Find out how to identify and maintain the right type of bearings in your projects

Above The anatomy of a ball or roller bearing is quite simple. It usually consists of a grooved inner ring (or race) with ball bearings or rollers set around it and held in alignment by a cage. An outer ring holds everything together, and the sides can either be shielded, sealed, or open. Sometimes, the shaft itself can be the inner race, as is shown in this picture

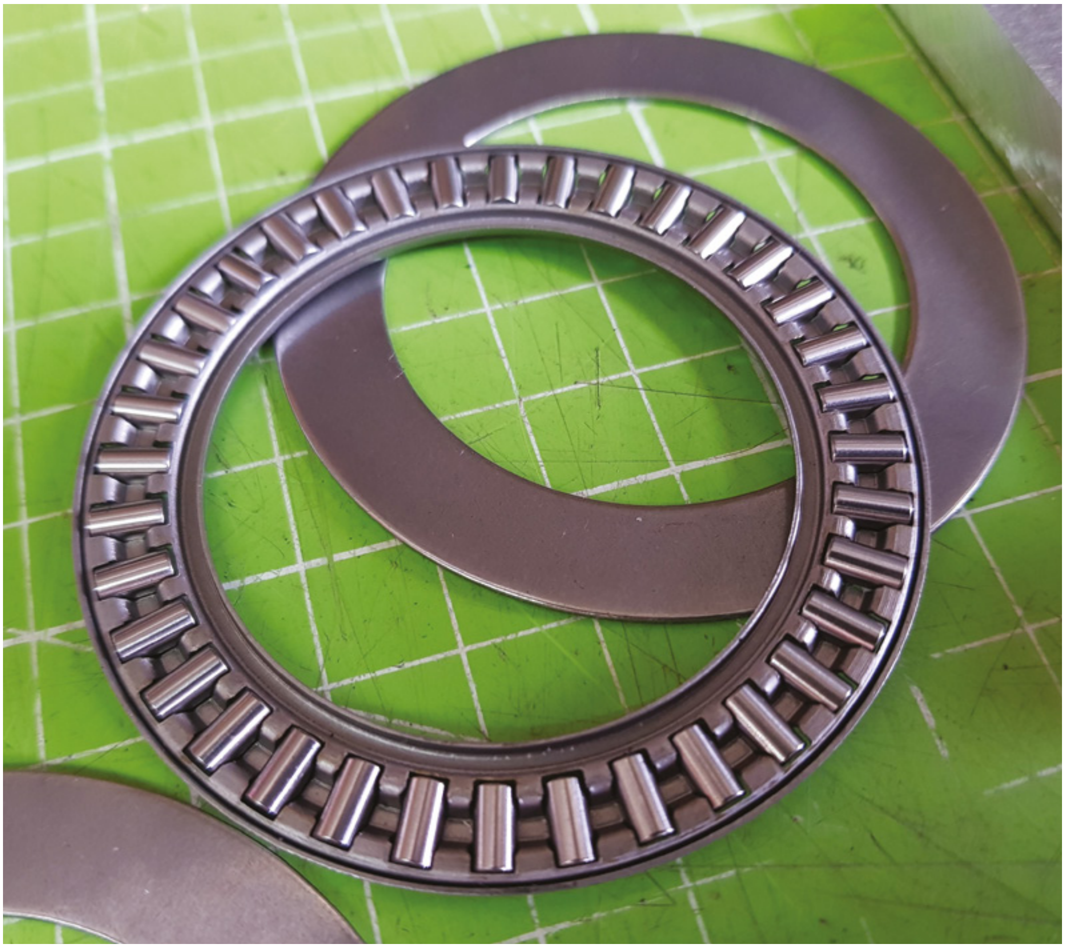
Credit
Klaudia P

Bearings and bushings are everywhere, but most people don't think about them until they stop working. When bearings are worn or damaged, they cause vibration, noise, and inaccuracy. Sometimes failure is a maintenance issue, and sometimes it's caused by someone choosing to use the wrong type of bearing to do a job. If you spend a little bit of time looking into the different types of bearings and how they work, you can save yourself time, and even improve your existing tools by replacing sub-standard bearings with better quality alternatives.

As the name suggests, a bearing is something that bears a load in a mechanical system. The bearing might be used to keep a revolving shaft aligned, reduce friction between two moving parts, or simply prevent excessive wear between two surfaces. At its simplest, a bearing can be nothing more than smooth metal with no other moving parts, or it can be a complex configuration of ball bearings, rollers, pressurised fluids, or even opposing magnetic poles. With all of these different types of bearing, it can be tricky to know which choices to make when it comes to maintenance or selection.

BEARINGS, BUSHINGS, AND SLEEVES

The simplest form of bearing is a plain bearing, which is also called a bushing or sleeve bearing. It's essentially a well-engineered hole made from



Dr Andrew Lewis

@monkeysailor

Dr Andrew Lewis is the owner of **Shedlandia.com**, a restorer of old tools, a fabricator for hire, a research scientist, and a founder member of the Guild of Makers.

Left
It's not always this easy to see the internal workings of a bearing, but this roller thrust bearing is obviously designed to take only an axial load. Any sort of radial load would make the stack of rollers bind on their housing. To use this bearing with a shaft, you need to add an additional bearing to take care of the radial load

a smooth, hard-wearing material like bronze. Plain bearings tend to be quieter than ball or roller bearings, and are a good choice when you have something that doesn't need to spin at high speed, or when you want the motion of a shaft to be extra smooth. Plain bearings usually need lubrication to run effectively, and it's important that regular maintenance is carried out to top up the lubrication and prevent excessive wear.

You might occasionally see what's called a babbitt bearing, which is a bearing with a surface that gets poured in situ using a soft, low-temperature alloy called babbitt. Although babbitt is described as a 'soft' alloy, it contains hard-wearing crystals that support the shaft while the softer babbitt alloy gets deformed. The deformation of the babbitt creates a pathway between the harder crystals that helps lubrication. Pouring your own babbitt bearings is possible, but not for the faint-hearted.

When you're choosing a bearing for a project, one of the biggest challenges is understanding the numbering system that bearing manufacturers use. There are some ISO (International Organization for Standardization), JIS (Japanese Industrial Standards)

> "Plain bearings tend to be quieter than ball or roller bearings, **and are a good choice when you have something that doesn't need to spin at high speed**"

and ABMA (American Bearing Manufacturers Association) guidelines that can help you decide what a bearing is, although sometimes you'll just have to dig through technical documents to find the exact details. Generally speaking, JIS follows the ISO standard, and the ABMA uses imperial values. However, things are never straightforward, and there are many kinks, standards, and abbreviations that make the system challenging.

IT'S ALL VERY SIMPLE, EXCEPT WHERE IT ISN'T

The first number or letter in a bearing number is usually a prefix that tells you the type of bearing, unless the sequence starts with an R, in which case it's an imperial bearing. Imperial bearings are measured in 1/16ths of an inch, and the number →

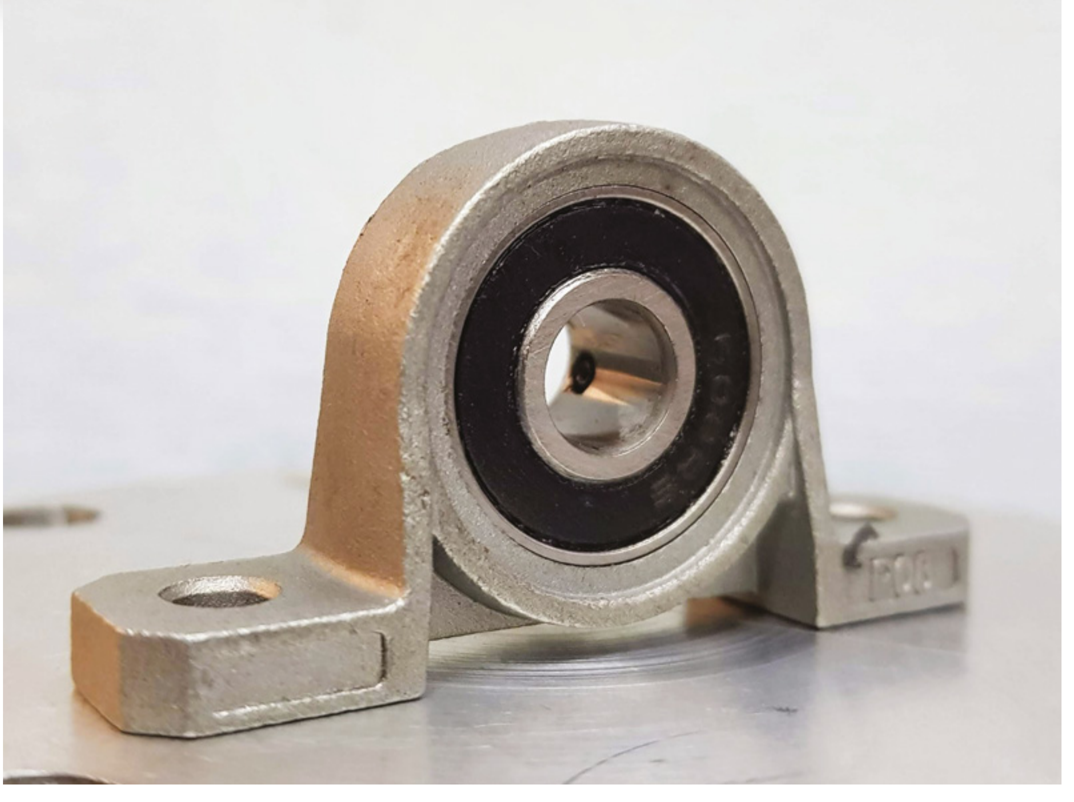
QUICK TIP

Not all bearings are made from metal. Some bearings and bushings are made from felt, leather, or durable plastics.

following the R is the shaft diameter in 1/16ths of an inch. So a bearing with a number beginning R8 would have a shaft 8/16th, or ½ an inch in diameter. Assuming that it isn't an imperial bearing, the letter or number might be one of the following:

Value	Type
1	Self-aligning ball bearing
2	Spherical roller bearing
3	Tapered roller bearing
4	Double row deep groove roller bearing
5	Thrust bearing
6	Single-row deep groove ball bearing
7	Single-row angular ball bearing
8	Cylindrical roller thrust bearing
C	Toroidal roller bearing
N	Cylindrical roller bearing
QJ	Four-point contact bearing
T	Tapered roller bearing

This list isn't exhaustive, and there are more letters for other types of bearing. Manufacturers are also free to add their own numbers or letters to signify proprietary bearing technologies. You're probably starting to see why this is so confusing, but



Above
Most bearings have a similar anatomy. They have an outer race, an inner race, a cage, and a ball or roller. The inner and outer race are the surfaces that the balls or rollers move against, and the cage holds the balls or rollers in place so that they don't bump into each other. The inner and outer race might have grooves, or they might be smooth. If they're grooved, then the edges of the grooves are called the shoulders

Right
If you need to fit a bearing with the minimum of fuss, consider using a pillow (or plummer) block. These blocks are ready-made metal fittings that hold bearings and bolt them onto surfaces without the need for complex machining

it's about to get even more ambiguous, because the next digit in the sequence tells you about the hardness of the bearing, but it isn't always present.

The next two digits refer to ISO sizes for the bearing, with the first digit being the width or height, and the second digit being the outer diameter of the bearing. More confusion ensues as we realise the numbers here are coded, with the smallest diameter being 7 and the largest 4, and the height values and number range differ depending on the type of the bearing. Suffice to say that it's easiest to look online at the ISO explanation for this, as it requires several large tables to explain in a meaningful way. These two digits are sometimes missing entirely from the bearing number, with the next one or two numbers referring to the size of the shaft that the bearing will take. For roller bearings less than 10 mm, there will be a number indicating the diameter in mm. For sizes of 10 mm and over, the numbers are in a code that starts with 00 for 10 mm, 01 for 12 mm, 02 for 15 mm, and 03 for 17 mm. From 04, the code goes to 20 mm and then increases as a multiple of five for each step.

To give a real world example of this, you can take a bearing number and see what you can figure out from it. The 608ZZ bearing is sometimes known as a 'skate bearing', because it's used in roller-skate wheels. We can see from the number 6 that the bearing type is a single-row deep groove ball bearing, which makes sense because the deep bearings mean that it can handle some axial load as well as radial load, and that's good for a skate wheel. We can also see a ZZ →

> "Manufacturers are also free to add their own numbers or **letters to signify proprietary bearing technologies**"

Above
This tapered roller bearing is better suited to an axial load than a ball bearing or angular bearing, but the extra surface contact increases friction and makes it less efficient for high-speed running. Choosing a bearing is often a case of weighing the advantages and disadvantages to find the best compromise

Right
Not all bearings are completely encapsulated – some are designed to be taken apart for maintenance, and others are only held together by the load that they support

Above
Flanged bearings have a lip on one side that butts against a flat surface, holding them in place. In this scooter fork, the wheel acts as a spacer to stop the bearings from coming loose. Fitting them was a matter of drilling the correctly sized hole and pushing them into place

suffix to the number, which tells us something about the design of the bearing. Unfortunately, each bearing manufacturer can essentially make these values up, but they do pretty much agree on the meaning of some basic suffixes. ZZ means that both sides of the bearing are shielded. Add to this that the 608ZZ has an internal diameter of 8 mm, and we're almost done with everything that this number can tell us. We know the internal diameter is less than 10 mm, so the size is represented by a single digit, so that leaves us with a 0 left over after the 6. That tells us it's a light-duty bearing. To summarise this section, it's a horrible confusion of numbers, and you are advised to take a look at the ISO standards, and browse through bearing catalogues to get a definitive answer.

CUT **AND THRUST**

The direction of the load applied, relative to the bearing, determines the type of bearing you need. Most bearings are designed to deal with a mainly radial load, where the force is applied at a right-angle to the shaft (like a roller-skate wheel). When a significant force is being transferred axially along the shaft (like the shaft of a drill-press), you need to use an axial bearing to bear that load. Axial bearings are also commonly called thrust bearings, and come in lots of different flavours including needle, roller, tapered, and plain. Angular bearings are designed to handle both linear and radial loads, and are a good choice where multiple bearings are impractical.

LOW SPEEDS FOR BUSHING, HIGH SPEEDS FOR BEARINGS

Now that you've figured out what your bearing actually is, and decided that you never want to try to decipher a bearing number ever again, you can think about mechanical placement. There are special presses and tools to fit a bearing, but if you don't have them, you can take the brute force approach of a mallet or a bench vice and an appropriately sized piece of pipe. The important thing is to apply force across solid parts of the bearing shell, not through the bearings themselves. You might find that cooling metal shafts and heating outer mounting blocks will make the bearings slip into place more easily. Don't be tempted to heat or cool the bearing itself, as not all types of bearing deal well with thermal extremes. Removing a bearing can be done with a nut and bolt, a length of tube, and a few washers. It's just a matter of tightening the bolt through the tube and the washers so that the tightening thread pulls against the bearing and levers it free.

If you are just replacing a bearing because it's worn out, you don't have to replace like-for-like. Try to consider the type of wear that's happened, and the advantages or disadvantages of other types of bearing in the same situation. As an example, consider the linear bearings that move the print head on a 3D printer. On budget printers, these are often LM8UU ball bearings (UU indicates that these are sealed bearings, LM is for linear motion, and 8 mm is the diameter). These bearings are functional but

> If you are just replacing a bearing because it's worn out, **you don't have to replace like-for-like**

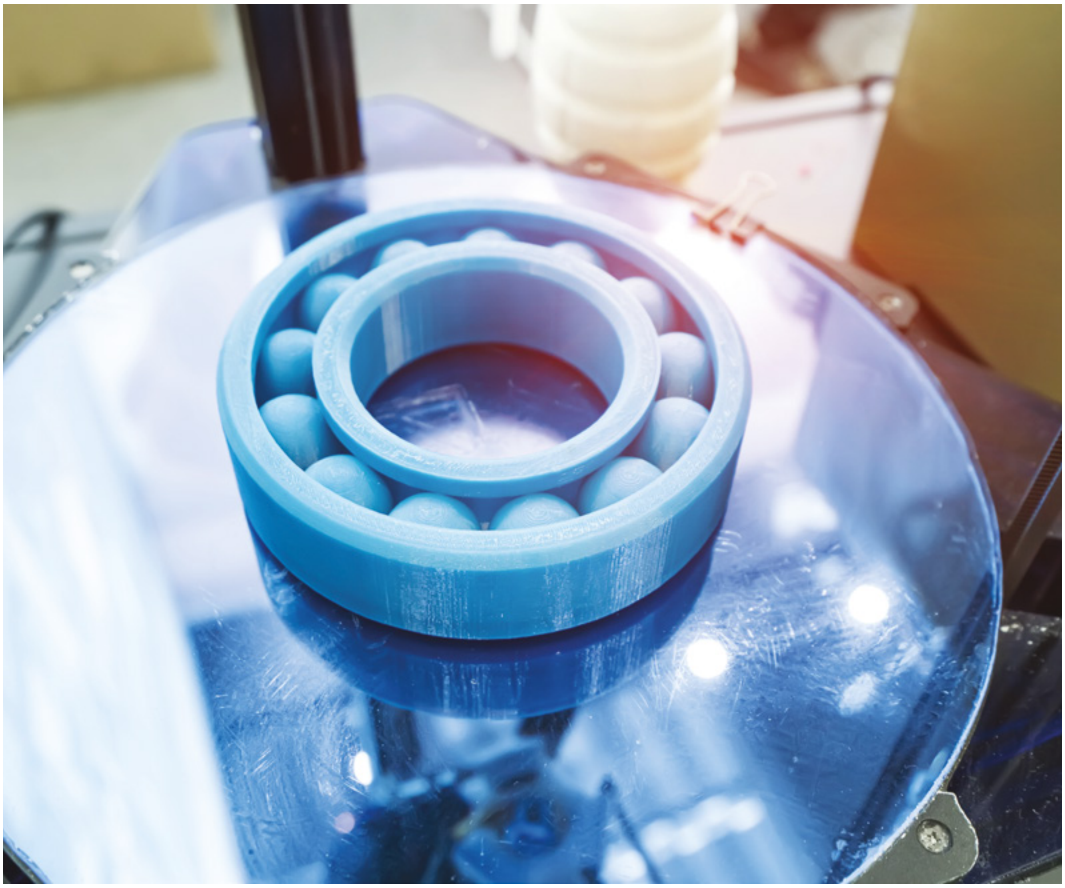
noisy, they have a poor tolerance, and will wear out quite quickly. Linear bushings are more accurate and quieter than LM8UU bearings, but it isn't just a matter of swapping them out and continuing as before. You will need to readjust your printer's shafts to make sure they're spaced exactly, because linear bushings are much less forgiving when it comes to alignment. If the shafts are slightly out of parallel, the carriage will start to bind. The frequency, quantity, and type of lubrication you'll need to use on the shafts will also probably change. In some cases, you might even have to modify the printer chassis to accept the bearings.

YOU GET WHAT YOU PAY FOR

The old saying goes that money makes the world go around, and it certainly has an effect on the rotation of machine tool shafts. You've probably seen low-cost mini lathes on eBay and other sites. If you own one of these lathes, you'll know that they're inexpensive for a reason. When they're set up properly, they're not bad machines for light work, but they need a few days of tinkering and upgrades to get them into a reasonable state. One of the biggest flaws with these lathes is that they typically use ball bearings in the headstock to save money. Changing these bearings out for tapered roller bearings will improve the quality of finish you can get from the lathe a great deal. Ball bearings will do the job, but they're not the best choice for the end-user. If you find a manufacturer that produces 'professional' and 'domestic' versions of a power tool, you'll probably find that the only internal differences are that the professional tool uses better bearings or bushings.

QUICK TIP

Some bearings can only support a load in one direction. It's common to stack multiple bearings together on a shaft to get the desired result.



Left
It's tempting to believe that bearings are always made from metal. Some bearings might be plastic or have plastic seals, and others might be made from ceramic. It's worth remembering that if you're pushing a bearing particularly hard or placing it somewhere hot, you might find the wrong type of bearing will shatter or melt unexpectedly

At a glance: Multimeters

What you'll find on the ultimate electronics measuring tool

Ben Everard

@ben_everard

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

The multimeter is one of the most universal electronics tools. As the name suggests, it allows you to measure many things. At the very least, your multimeter should measure voltage, current, and resistance, but many can measure far more than this. Let's take a quick tour of a common multimeter. Some multimeters have additional features not shown in this one. For example, USB out lets you connect your meter to a computer and take a continuous reading from the probes – great if you want to see how something changes over time.

1 **Selector wheel** Almost all multimeters follow the design of having a wheel in the middle that lets you select different options. You're unlikely to find any design of meter at a maker level that doesn't follow this layout.

2 **Display** This shows the current reading. Keep an eye out for what unit the number is in – this might be displayed on the screen, or it might be based on what position the selector wheel is currently in.

3 **Voltage measurement** This meter is 'autoranging', which means that there's one position for voltage reading, but other meters may have several positions which can each read a range of voltages. If you're unsure what voltage you're expecting, start with a high voltage range and work downwards. Voltages are read in parallel to the circuit you're measuring. So, for example, to measure the voltage across a resistor, place the probes either side of the resistor. Bear in mind that autoranging doesn't mean arbitrarily high ranging. Check your meter's limitations (and your own understanding of electrical safety) before plugging it into a circuit that has more than a few volts.

4 **Current measurement** Like voltage, current may be 'autoranging' or not – on this multimeter, they autorange, but not completely. Unlike voltage, current readings are taken in series with the circuit, so to take a current reading, you need to break the circuit, then use the probes to re-complete the circuit.

5 **Resistance measurement** Again, resistance may or may not be auto ranging. Resistance measurement is taken with the component not connected in the circuit; just put the probes on either leg and read the result off the display. This is a good option if you're unsure of how to read the colour bands.

6 **Continuity meter** This doesn't read out on the display, but beeps if there's a connection between the two probes – it's great for checking a circuit for dodgy soldered joints or problems with a breadboard. If your multimeter doesn't have this, you can use the resistance measurement to similar effect, just looking out for very low resistances.

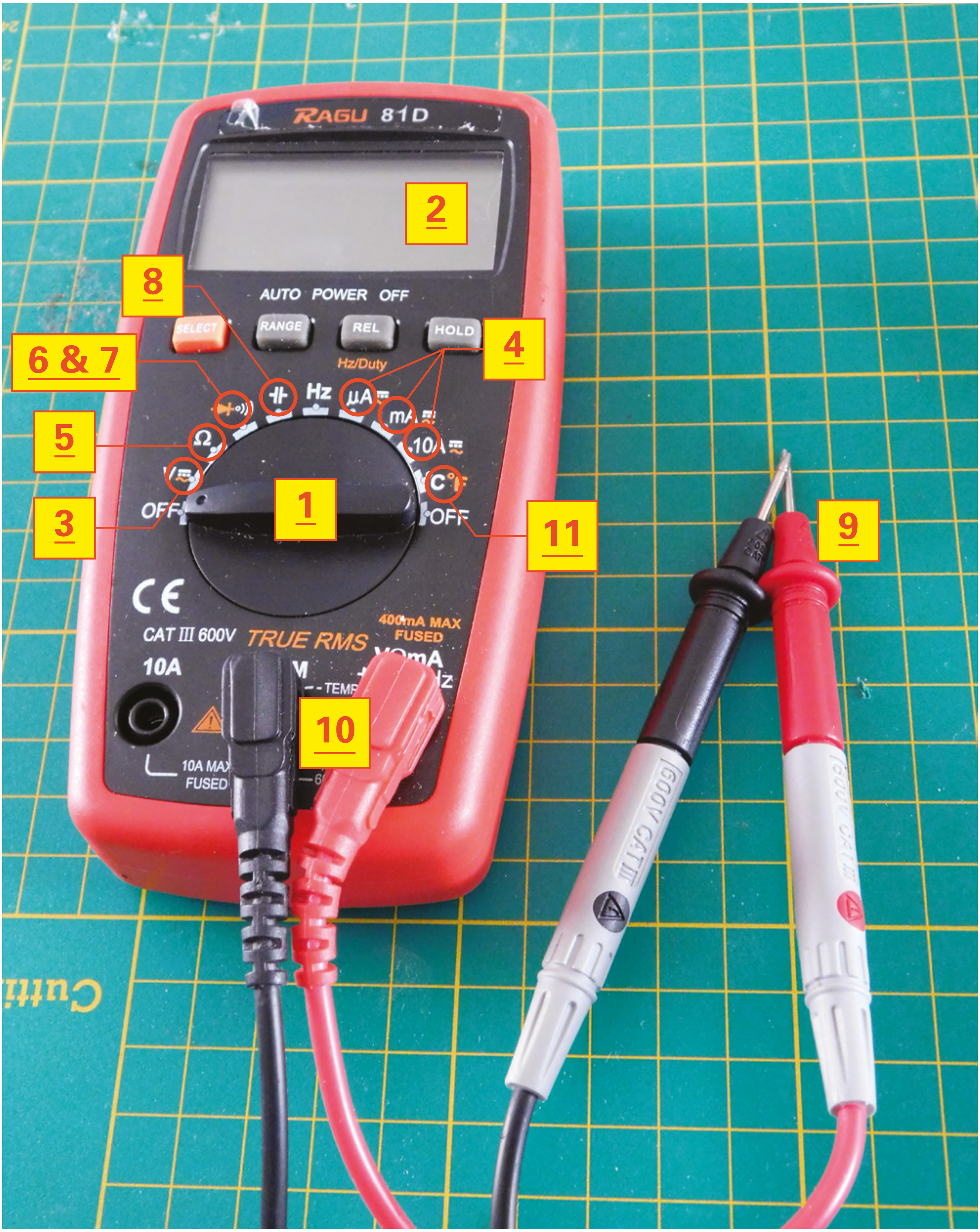
7 **Diode checker** This will test a diode and report its forward voltage on the screen. It's great for checking you have a diode the right way around!

8 **Capacitance checker** Like resistance measurement, but with capacitors!

9 **Probes** These are what you poke into the circuit to take readings. You can also use crocodile clips to take measurements without you having to hold them.

10 **Probe connectors** Your multimeter may have more than one way of connecting the probes – typically one for low currents and one for high currents.

11 **Temperature** Many multimeters have the ability to read temperature probes, but most don't come with the necessary probes, so if you want to use this, you'll have to purchase these separately. □


RAGU 81D
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9
CE
CAT III 600V
TRUE RMS
400mA MAX
FUSED
10A
10
10A MAX
FUSED
600V CAT III

Make your 3D prints shine

Glenn Horan

@BatGlenn13

Glenn is a software developer by day and a 3D printing enthusiast by night. Rumour has it that building and troubleshooting cheap Prusa clones is what caused him to go bald before his years.

A variety of techniques to beautify the roughest of 3D prints

3D printing is awesome. Do you know what's not awesome? Layer lines. For functional prints, this unique texture isn't much of a problem, but there are many out there who strive to get a professional finish on their creations. After all, Stormtrooper helmets aren't covered in horizontal lines, are they? This guide will walk you through some of the essential techniques to transform your prints from draft quality to something that you'd never know was 3D-printed.

PARAMETERS AND SETUP

Achieving high-quality finishes on 3D prints begins before the printer has even been turned on. The most obvious consideration for impacting the surface quality is the layer height – a smaller layer height will result in much smoother prints and a much higher-resolution model, but will take much longer for your object to print. In contrast, a larger layer height will print quicker and theoretically result in stronger objects, but will have more obvious lines and less detail.

LIFE'S A BEACH

Sanding is the single most widely used and effective method of getting a perfect finish on your 3D-printed creations. It is used in conjunction with virtually every other finishing technique, with the notable exception of vapour smoothing, and will work with all materials as well as filler and/or epoxy resin if you've used these on your print. If done carefully,

YOU'LL NEED

- **Flush wire cutters**
- **Sandpaper, variety of grits**
- **Spray filler primer**
- **Low viscosity epoxy resin**
- **Cheap disposable paint brushes**
- **Tin-foil**
- **Small disposable trays** (a plastic takeaway container is ideal)

Left
Benchy fresh off the build plate using a 0.24 mm layer height. This is our starting point

sanding can preserve the most detail of all the techniques listed. It's also very cheap and with a bit of patience can get amazing results, even a near mirror finish if you have the time, patience, and the inclination to work up to 2000 grit sandpaper.

With any sanding, start with the lowest grit sandpaper to get rid of the worst of the imperfections, and then work your way to the highest grit. Due to the nature of 3D printing materials being sensitive to high temperatures (particularly PLA), it is recommended that you go slow when sanding your parts, and use wet sandpaper to minimise the amount of heat generated from friction (this can easily melt and distort your model). In a circular motion with 240–320 grit sandpaper, move over the surface of the 3D print until it feels uniformly smooth (you may want to start at an even lower grit for particularly rough areas). You should be able to see any areas you've missed as you sand, and imperfections in the surface should become more obvious. Remember that any areas missed while sanding with a lower grit sandpaper will take much more time to smooth in subsequent steps, so it's worth the time investment in the early stages of the process.

Be careful not to remove too much material where details are protruding from the print – using Benchy as an example, this would mean taking particular care around the round holes at the front of the ship and the lip at the top of the hull. Repeat the sanding process with higher and higher grit paper until the desired finish is achieved. Depending on the part, this may be after the first pass with the low grit stuff, or after several hours graduating through the grits until you are at 2000. →

> "Be careful not to remove too much material **where details are protruding from the print**"

BENCHY

For this guide, we're going to use the 'Hello World' of 3D printing – Benchy. The strangely adorable Benchy was uploaded to Thingiverse in April 2015 by Creative Tools to provide an aesthetically pleasing stress test for 3D printers. It showcases a number of different challenging features that will help users to push their printers and identify settings that need tweaking to get the most out of their slicer software. As Benchy is a 3D printing icon, we thought it'd make a great model to showcase our finishing techniques.

QUICK TIP

Orienting your print on the build plate so that it has the least support material will save you filament and reduce post-processing work.

FILLER PRIMER

So you've put in the extra printing time to get a high-resolution model, and your piece doesn't look half bad straight off the print bed. If you need to look fairly closely to see any of the print lines and your model lacks any major flaws, it's possible to get a decent finish using a simple spray can. Long before 3D printing was a thing, filler primer was sold to cover minor surface imperfections and provide a good base for paint to adhere to. A surface that is covered in subtle shallow lines is the perfect use case for filler primer, with the bonus that it'll prepare the printing surface for painting. While this is one of the pricier options in this guide, it certainly won't break the bank at around £7–£10 per 400 ml. This technique works great with sanding – the filler will fill any recesses in the print between layers, and the sanding will wear away any raised areas.

FLUSH FRIENDS

The first tool we reach for when a print is finished is our flush wire cutters. It's no surprise that they're included with most 3D printers as they make the job of removing supports, brims, stringing artefacts, and other imperfections a breeze. They're also far safer than the alternative, which is to saw at excess extrusions with a razor-sharp craft knife (we've seen a few gory pictures on 3D printing forums where this technique has gone wrong). A quick pass over your print with a set of flush wire cutters is an essential first post-print step to finishing a 3D model.

PATIENCE IS KEY

As with spray paint, filler primer should only be used in a well-ventilated area. Gloves and a face mask are also recommended. Prepare the print by giving it a quick rinse to remove any surface dust or particles, and allowing it to dry. If it's small enough, you can use a painting handle to easily coat the entire print without having to touch it – though if it's too big or irregularly shaped, it's fine to just do one side at a time. To cover the print evenly, hold the can approximately 30 cm away and spray while moving it from side to side, and not changing direction while spraying on the print. As with the sanding, patience is key here. A few passes will be needed to coat the print and if you've missed any detail, don't be tempted to move the can closer and focus on that one area – this will result in pooling, loss of detail, and an inconsistent finish. Once the first coat is dry, have a close look to see if the desired result has been achieved. If there are still thick layer lines

Above With a little sanding, Benchy's looking better already

Right It may not look it due to the scratched-looking surface, but the hull of this Benchy is incredibly smooth to the touch visible over most of the print, simply apply another coat. If there are specific areas that still look a little rough, then it may be a good idea to get the sandpaper out and get to work sanding those down.

> Try to rub off as much excess filler as you can **so it's almost exclusively in the recesses**

A DEEPER FILL

While filler primer is generally good enough for filling in layer lines and obscuring small imperfections, there are times when you'll need to fill in larger gaps. This is almost certainly the case when joining two or more 3D-printed parts – subtle warping and slight deviations from perfect calibration can lead to parts not lining up correctly, or not sitting flush when lined up against each other. There is such a huge variety of fillers that it'd be impractical to cover all of them here, but important attributes are that the filler is easy to sand and that there is minimal to zero shrinkage as it sets. Many people in the community recommend Bondo, which is a plastic-based filler commonly used in automotive body repair jobs, but good results can be achieved using cheap generic filler from Amazon or even bargain stores on the high street. We've used a generic all-purpose filler that is suitable for stone, wood, plastic, etc.

Below
Most filler primers come in bright colours so you can see any areas you've missed

With our Benchy example, there are still some deeper layer lines on the hull that are prime candidates to showcase our preferred way of using filler. With gloves on, simply put some of the filler into your hand and rub into any deep recesses on your print. Try to rub off as much excess filler as you can so it's almost exclusively in the recesses. Once the filler has dried (the amount of time will depend on the type of filler and the brand), it's time to get the sandpaper out again. Luckily, most filler is designed to sand well: so as long as it's 100% dry, you should be able to get a nice smooth surface again without too much effort. →

QUICK TIP

Three to four coats of filler primer do a great job of filling in layer lines.

Below
Acetone baths can create great-quality surfaces – just make sure to keep one eye on the reaction at all times!

ACETONE VAPOUR BATH

If ever there was a name for a process that sounds grander than it is, it's an acetone vapour bath. This involves putting your print in a sealed container with a pool of acetone at the bottom. Due to the volatility of acetone and the inherent nature of gases, the container will fill up with acetone vapour, enveloping the print, and gently melting the outer layer. Acetone itself is cheap and readily available thanks to its role as nail polish remover. The results can be great, but the huge caveat with this technique is that it only works with ABS, which can be difficult to work with relative to PLA unless you have an enclosed printer. Due to flammability and volatility of acetone, this technique must be carried out in a well-ventilated area, and far from any naked flames or sources of high temperatures. The results can also be pretty inconsistent – some people have reported waiting hours with no results; others report that their print melts before any smoothing has been seen. If you print a lot of ABS, but dimensional accuracy isn't so important for you (not much overlap in that Venn diagram), then acetone smoothing may be for you.

QUICK TIP

Filler is great for seams between two printed parts.

PRECISION SANDING

There are a number of tools you can use here to help you on your sanding journey – cardboard nail files are particularly good for getting into crevices, especially if they're trimmed down into thinner sticks. Thingiverse has sanding blocks of all shapes and sizes, but if you're stuck for a particular shape, you could always design and print it yourself.

EPOXY COATING

This is potentially the messiest of all the methods listed here, but you can get some great results (see right). The idea behind epoxy coating is that you apply a low-viscosity epoxy resin to the surface of a print and let it flow into all the gaps and imperfections. Once it sets, you should have a smooth solid shell that will hide all the layer lines and even fill in some of the larger gaps and imperfections of your print. The big downside is that the epoxy can pool in any recesses or angles in your print, making corners less sharp and obscuring details on the surface. The outer coating can be relatively thick (compared to say a coat of paint), so it's not ideal for functional prints that require dimensional accuracy. Finally, epoxy resin is toxic and can be very messy if not handled carefully. Avoid contact with skin at all costs, use gloves, use in a well-ventilated area, and appreciate that whatever it comes in contact with will likely be ruined, so don't be working with it in your Sunday best.

Put on your gloves, open some windows (or work outside if possible), and prepare any surfaces that are being worked on by liberally applying newspaper and/or plastic sheeting, so that the liquid epoxy resin won't soak through and ruin your possessions. Start with a disposable container (both the plastic and tin-foil containers that takeaway food comes in are ideal), and glue a small platform in the centre that your print can rest on. Small 3D-printed shapes work great (even old calibration cubes), and you can customise them for the needs of the project – just make sure it's smaller than the base of your print to allow the epoxy to pour over its edges without coming into contact with the platform. After mixing the component parts of your epoxy in a separate container, if you're feeling brave, simply pour the mixture over the print and allow it to flow over the sides into the disposable container below (this only really works if you have a very basic shape to be finished). If you are working with something a little

Right Our Benchy after sanding, filler primer spray, and filler. Note how the filler is most prevalent in the horizontal lines that remained after the previous processes

QUICK TIP

Remove excess epoxy from your brush and use it to wick up any areas where it has pooled on your print.

Below
The surface is so mirrored that you can take a selfie in it

Above
Ohh shiny… a coat of epoxy gives a great mirrored finish all over your print, while strengthening the outer shell and making it watertight

Left
Check out that uniform finish on the hull – a product of sanding, filler primer, filler and, of course, a base coat of paint from an airbrush

more complex, use a cheap paintbrush to coat the whole model with epoxy resin, being careful to avoid pooling in corners and recesses (needless to say, the paintbrush will be ruined after this one use, so it's best to use the cheapest you can find). Set onto the platform you prepared earlier to allow any excess epoxy to drip into the plastic container and leave to dry for several hours, or if possible overnight, before sanding or painting.

As you've probably guessed, the best results will be achieved using a combination of different techniques shown here, and which one(s) you choose to use will depend entirely on the model that you have and the result that you're trying to achieve.

What you do after these finishing steps depends entirely on what you wish to do with your print. If it's a model to be painted, then applying a base coat straight onto your print with an airbrush or a spray can work great before painting in the details. If it's something that will be uniform in colour, we've had great results using a spray resin lacquer to get a strong, smooth, watertight finish. If you wish to preserve the colour of the printed material, and have done a particularly good job sanding (using over 2000 grit paper), a quick buff with a metal polish from your local supermarket is the final piece of the puzzle to get that coveted near mirror finish.

> "The best results will be achieved using a combination **of different techniques shown here**"

HackSpace
TECHNOLOGY IN YOUR HANDS

FIELD TEST

HACK | MAKE | BUILD | CREATE

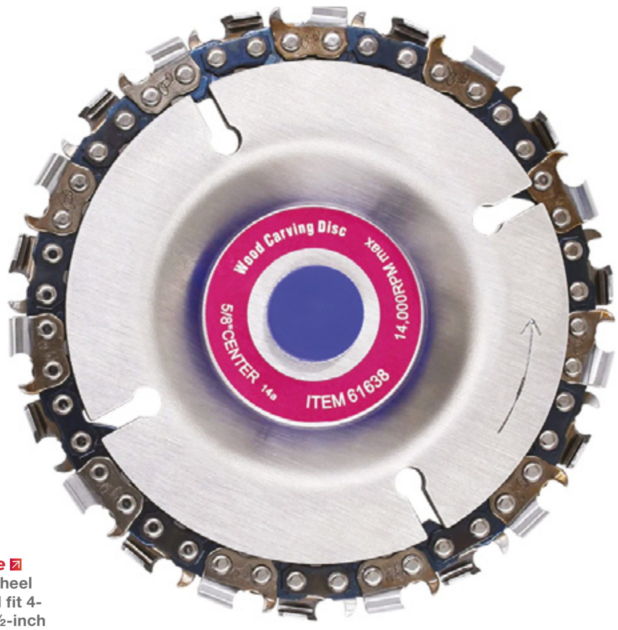
Hacker gear poked, prodded, taken apart, and investigated

REVIEWS

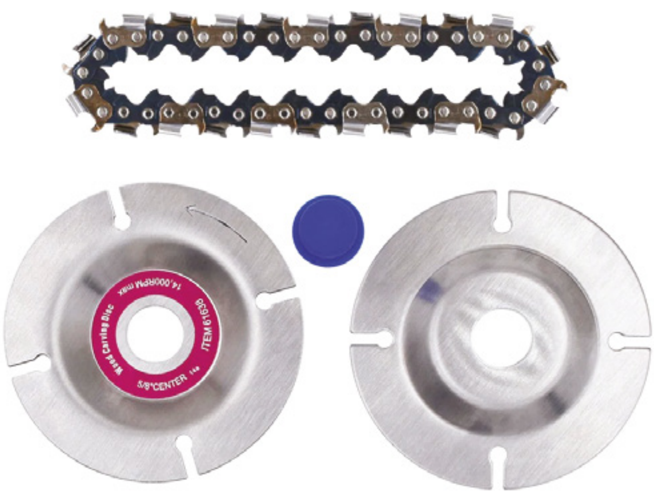
Chainsaw wheel

What level of risk will you accept?

By Ben Everard @ben_everard



Above This wheel should fit 4- and 4½-inch angle grinders



Chainsaws and angle grinders are both iconic tools. They're both used by the film industry to conjure up a particular feeling for a character – usually male – as particularly adept at working with his hands. Perhaps it's because they both have a tendency to spit out vast amounts of 'stuff'. Chainsaws render vast logs into piles of sawdust (and a few slightly smaller logs) in minutes, while angle grinders create a shower of sparks reminiscent of the 5th of November (or the 4th of July for our American readers). Why not bring these two tools together to create an uber-maker tool?

Well, from a safety standpoint, there's a pretty good reason, in that the safety features for each tool are designed for the risks that tool poses. A chainsaw can bite into wood, causing 'kickback' which throws the blade around (often at the user's head), and so they have a chain brake that should lock the chain before it splits your skull in two. With an angle grinder, however, perhaps the biggest risk is the disc shattering and sending shards at the user – to minimise the risk here, grinders have guards that should protect the user from these shards.

For a mere £6.58, we got a chainsaw wheel from the GOXAWEE Global Store on AliExpress to see just how much it terrified us.

The product page comes with the handy warning, "It is not advised to use the switch lock feature on any grinder. Doing so may result in serious injury or even death." There are two basic types of switch on angle grinders – some 'lock on', in that you turn them on and they stay on until you turn them off. Others have a switch that requires you to hold it in place while you grind – if you let go of the grinder, the power turns off. The exact way this works varies from manufacturer to manufacturer. Cheap angle grinders often have a slide switch with a locking 'on' position. These can be tiring to hold without locking them. Some more expensive angle grinders have a paddle switch that's easier to hold 'on', and often don't have the ability to lock them in the 'on' position.

STAYING SAFE

While this is undoubtedly good safety advice, it by no means makes the tool safe. Our biggest concern with this is that the disc has a tendency to 'bite' and pull on the user. In our testing, this was controllable, but it's very easy to imagine circumstances where it would bite hard enough to send the disc into something it shouldn't hit. You need to be constantly aware of the direction of spin, and the direction in which this will pull the disc if it bites.

At its best, this tool lets you shape wood very quickly and with better accuracy than we've been able to achieve with a chainsaw – it could find a very useful place in the world of power carving. However, the risks of a tool like this are very real and if anything goes wrong, it will go wrong very quickly. This is one of those tools that raises the question of how much risk you are willing to accept in order to make an object. There's no right answer here. This author is willing to accept occasional burnt fingers from not paying attention when soldering. He's willing to accept the risks with a properly set up angle grinder (guard in place and side handle in operation), and he's willing to accept the risk of simple chainsaw work. He's not willing to accept the risk of using this cutting disc again. After testing it out, he took it off his angle grinder, never to be used again (at least, not for its intended purpose – it might find a home as part of an art piece). Everyone has to decide the answer to this question for themselves.

You might think of this disc as useless, then, but that's not how we see it. Coming eye to eye with something the other side of the danger-line has sharpened our senses to risk, and what we have the skill and experience to use. These days, you can buy almost anything online, but just because you can, doesn't mean you should. We're all responsible for our own safety, and it's worth taking a few minutes to think about what this means to you. We can't cover ourselves in cotton wool and it's important to put the danger in context – the most dangerous part of using a hack or makerspace is probably the journey there, not the tools in the space – but plenty of people have been killed and seriously injured by power tools over the years, and many more have had lucky escapes.

Can this wheel be used safely? Maybe, but we're not willing to take the risk of finding out. That's our decision, and it's up to you to make yours. □

Left The teeth on this wheel make short work of wood – or anything else that gets in their way

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BEST OF BREED

ONLY THE BEST

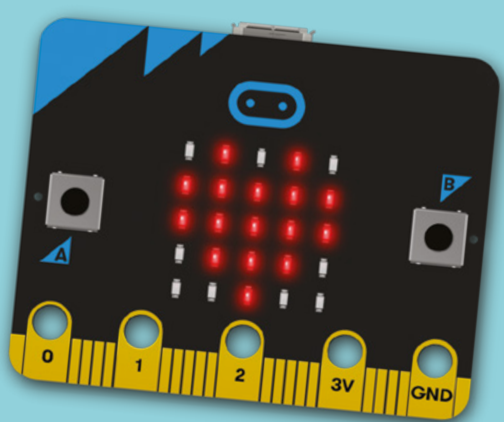
micro:bit prototyping accessories

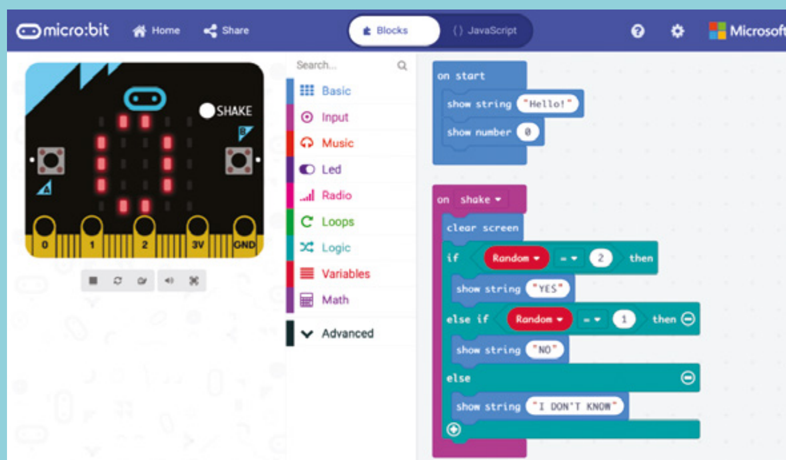
Products that allow you to get more out of your micro:bit

By **Marc de Vinck** @devinck

The micro:bit was developed as an open-source learning tool for the UK educational system. Fortunately for the millions of people in the DIY community, it has grown beyond the UK school systems and is available at a very reasonable price from almost anywhere you can pick up your favourite electronic components.

What makes this board popular besides the competitive price? It starts with the powerful ARM-based processor and ability to program it in MakeCode JavaScript and blocks, Python, Scratch, and many others. And no software installation is required. In addition, electronics enthusiasts have come to love the 25 built-in LEDs, two user-accessible buttons, radio and Bluetooth capabilities,





light and temp sensors, and on-board compass and accelerometer. It packs a lot into a board that's just about the size of a credit card. Be sure to check out the official site, **microbit.org**, to learn more about all the things this popular little board can do.

In this Best of Breed, we're going to take a look at some of the accessories available for the micro:bit. Specifically, we'll be looking at what you can use to start prototyping your own creations with the micro:bit, after you have learned about all the included components and sensors. Even though the micro:bit packs a lot of useful features, it's more than likely that you will eventually want to add more components such as motors and new types of sensors. And that's where this Best of Breed will help you to get started with exploring the possibilities of using the micro:bit in your projects.

Above There are many ways to program the micro:bit, including through the website

Adafruit CRICKIT for micro:bit vs Motor Driver Board v2

Get your micro:bit moving

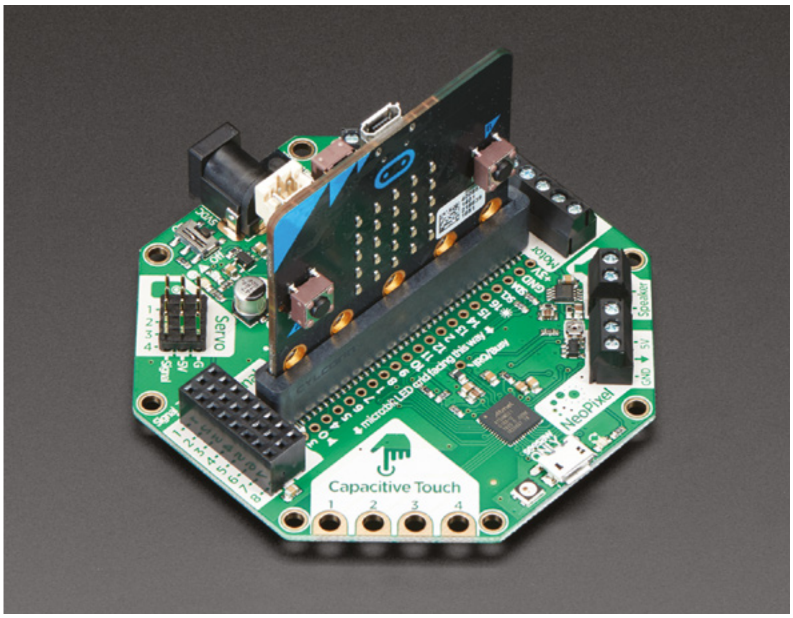
ADAFRUIT ◆ $29.95 | adafruit.com

KITRONICK ◆ £12.78 | shop.pimoroni.com

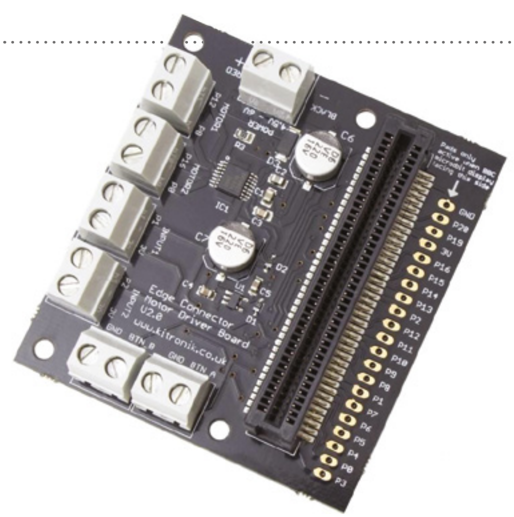
The Adafruit Creative Robotics & Interactive Construction Kit [aka CRICKIT] system has been a popular add-on board for both robot builders and DIY electronics enthusiasts alike. We first used a CRICKIT system with Adafruit's Circuit Playground board, followed by a version compatible with the firm's Feather boards. We were really impressed with how much functionality and ease of use it brought to those systems.

Adafruit also offers a CRICKIT board that is compatible with your micro:bit, making adding a motor, servo, relay, or LED strip as easy as plugging the micro:bit into the CRICKIT's edge connector port. The board also features capacitive touch breakout pads and a Class D 3-watt max audio amplifier with speaker connector.

Adafruit is able to add all this by powering the CRICKIT with 'seesaw', its I²C-to-whatever bridge firmware. This allows the user to control a variety of inputs and outputs with just two data pins. And all the required timers, PWMs, and sensors, are all offloaded to the on-board processor. It's a great system for expanding the abilities of your micro:bit. □



Above
Easily access all the power of the micro:bit



The Motor Driver Board v2 allows anyone to easily control two motors, in both directions, and gives you access to additional pins of the micro:bit. It's a great way to build your first robotics platform. The board also features a regulated 3V power supply. All the pins for the micro:bit are broken out to pads that run along the edge of the board, making it really easy to add your own circuits and components. If you want to build a micro:bit-based robot, this is a good starting point. □

VERDICT

Adafruit CRICKIT

A great system for breaking out the power of the micro:bit.

10/10

Motor Driver Board v2

A good board for powering motors.

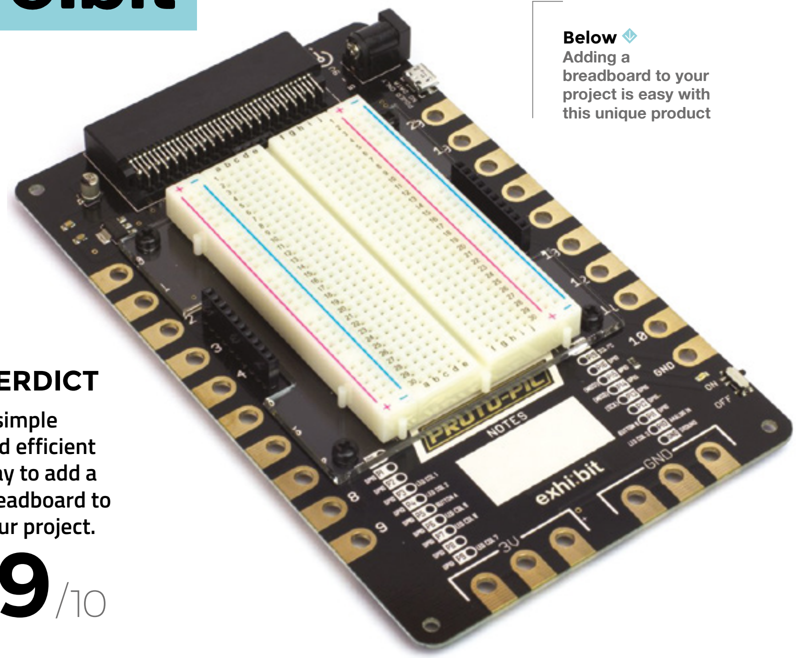
8/10

BEST OF BREED

exhi:bit prototyping system for micro:bit

Build custom hardware

PROTO-PIC £18 | proto-pic.co.uk



Below Adding a breadboard to your project is easy with this unique product

The exhi:bit prototyping system is an interesting accessory for your micro:bit. Plug in your board at the top, and you will have access to all the pins in the headers. There is a prototyping area for adding a half-size solderless breadboard or to solder together a more permanent circuit. The exhi:bit even has a small space next to the prototyping area to write down some notes about the circuit. There is also a 9V barrel jack and micro USB port to easily add power to your prototype. This system is a really nice addition for anyone who plans on building a custom circuit with the micro:bit.

VERDICT

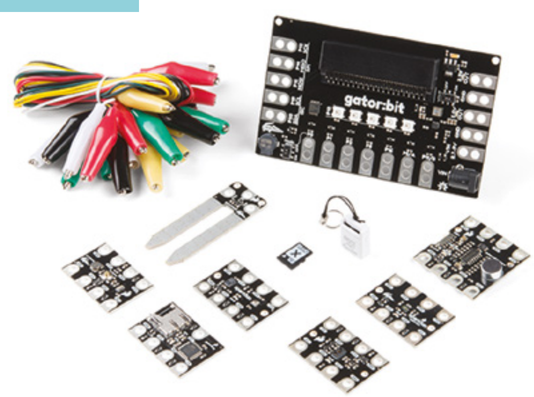
A simple and efficient way to add a breadboard to your project.

9/10

SparkFun gator:science Kit for micro:bit

Clip together, for science!

SPARKFUN $90 | sparkfun.com



SparkFun gator:science Kit for micro:bit is a collection of micro:bit-compatible breakout boards and sensors for anyone interested in environmental science. You start by attaching your micro:bit to the gator:bit, which adds voltage protection, I²C access, power, five addressable RGB LEDs, and more. The kit also includes a whole host of alligator-clip-compatible sensors including a microphone, UV sensor, soil moisture sensor, real-time clock, data logging, and an environmental breakout board.

The environmental sensor breakout board features a variety of environmental data, including barometric pressure, humidity, temperature, equivalent TVOCs, and equivalent CO_2 levels. Check out the product page for more information about the specific sensors and full documentation. It's a great kit to get you up and running fast with measuring and recoding environmental conditions on your micro:bit.

VERDICT

A good collection of components to get you started.

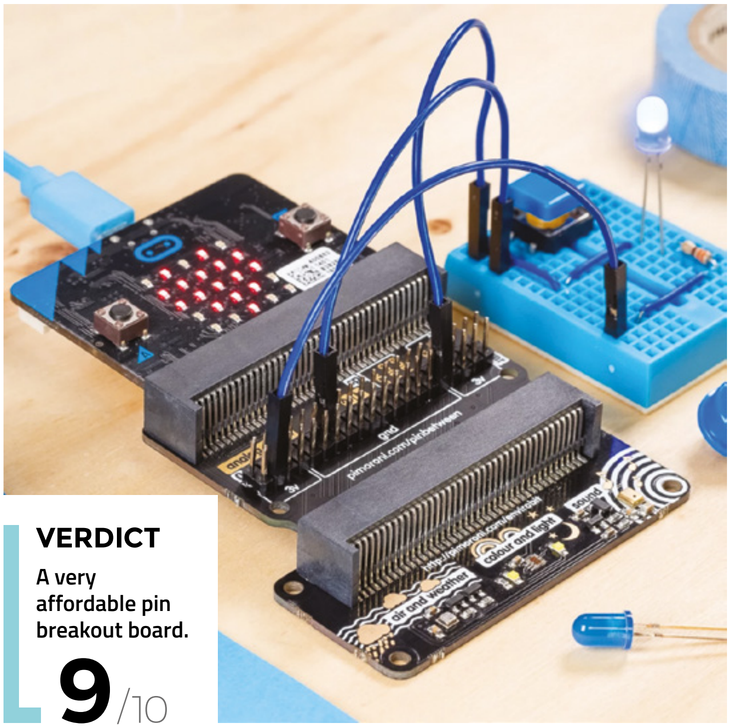
9/10

Pinbetween

Don't let a breakout hog the pins

PIMORONI ◈ **£6** | **shop.pimoroni.com**

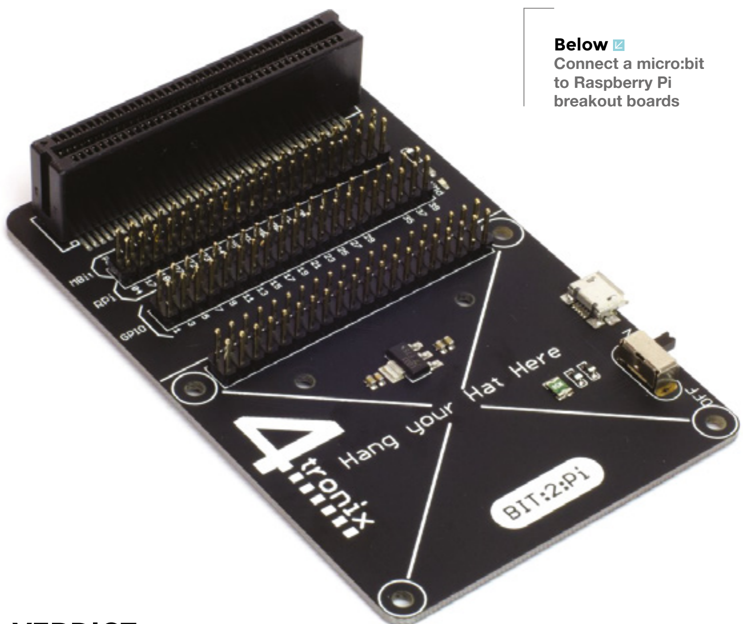
The Pinbetween from Pimoroni gives you access to all of the micro:bit's pins while still being able to connect another breakout board simultaneously. Why would you want to do this? The answer is simple. Let's say you want to connect something like an enviro:bit, as pictured, but you still need additional functionality. Typically when you plug your micro:bit into a breakout board, you lose access to the unused pins. That's not the case with the Pinbetween. Simply use jumper wires to connect up additional components to any pins that aren't being used. It's a really handy addition to your toolbox!



VERDICT

A very affordable pin breakout board.

9/10



Below Connect a micro:bit to Raspberry Pi breakout boards

Bit:2:Pi

HATs on a micro:bit?

4TRONIX ◈ **£14.40** | **shop.pimoroni.com**

The Bit:2:Pi allows you to use many of the breakout boards, HATs, and shields that you may already own for your Raspberry Pi with your micro:bit. Of course, some advanced HATs are not going to work since a Raspberry Pi is much more powerful than a micro:bit, but there are a lot of boards that will work just fine.

Even a Raspberry Pi HAT that relies on I²C and SPI connections should work. And if you need a specific pinout, you can easily do that with just a few jumper wires. Don't forget, even though a Raspberry Pi board might be compatible with your micro:bit, the code won't work. Fortunately, many boards are controlled by simple on/off sequences which easily translate to the micro:bit without too much effort. Check out the product page for updates on code and compatible HATs.

> "Fortunately, many boards are controlled by simple on/off sequences"

VERDICT

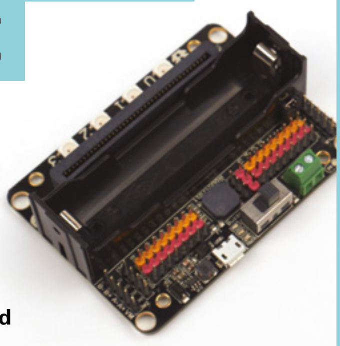
Use Raspberry Pi-based boards with micro:bit.

8/10

Robotbit - robotics expansion board for micro:bit

Add motors and servos

KITTENBOT $20 | kittenbot.cc



The Robotbit allows you to easily add motors and more to your micro:bit. It features the ability to drive standard DC motors, stepper motors, and servos. It also has an on-board buzzer and RGB LED, in addition to allowing you to easily access all of the micro:bit's pins. What we really like about this product is the addition of a 18650 battery holder, and charging and protection circuitry. This is great for a mobile robotics platform.

VERDICT

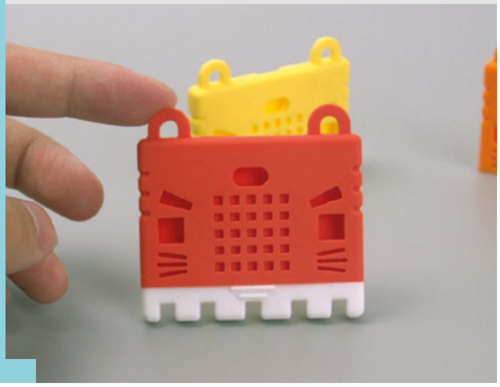
A powerful breakout board with integrated power.

8/10

KITTENBOT SILICONE **KITTY CASE**

KITTENBOT $6 | kittenbot.cc

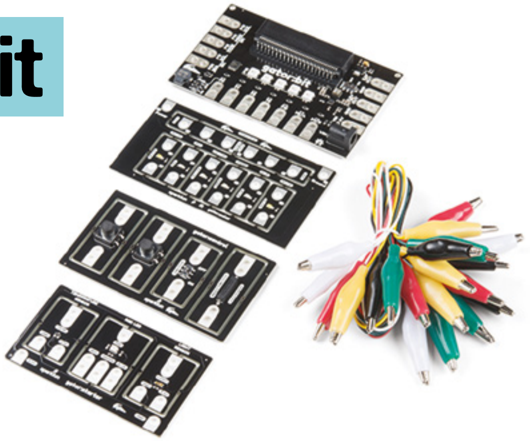
At some point, you are most likely going to want a case for your micro:bit. And why settle for just some plain case when you can get something adorable and functional? The Silicone Kitty Case from Kittenbot comes in two pieces: the top part protects the main part of the micro:bit, while a smaller section covers the bottom edge but still allows access to five of the pins. It's a fun and affordable way of protecting your micro:bit.



SparkFun gator:circuit Kit for micro:bit

Clip your circuits together

SPARKFUN $40 | sparkfun.com



VERDICT

A great addition when prototyping with your micro:bit.

10/10

The SparkFun gator:circuit Kit allows anyone to easily expand their micro:bit with a selection of useful components and sensors. The kit starts out with the gator:bit, which is a carrier board allowing you to plug in and access almost every pin of your micro:bit with alligator clips. It also features overvoltage protection, I²C access, additional power management, and more. One of my favourite additions is the five addressable RGB LEDs. You can never have too many LEDs!

There are several other boards included in the kit. The gator:control ProtoSnap features two buttons, an on/off slide switch, and a reed switch. Also included is the gator:color ProtoSnap board, which features a selection of LEDs and an integrated power rail. You'll also get the SparkFun gator:starter ProtoSnap, which adds a temperature sensor, light sensor, and RGB LED. Join these together with the included alligator test leads, and you'll be snapping and clipping your way to building your next project.

Can I Hack It?

A candy grabber?

What can you make out of this off-the-shelf toy?

Les Pounder

@biglesp

Les Pounder loves taking things to pieces and seeing how they work. He teaches others how to be makers and tinkerers at events across the UK. He blogs at **bigl.es**

YOU'LL NEED
Candy grabber

COST
£18.99

WHERE
hsmag.cc/lsUZCP

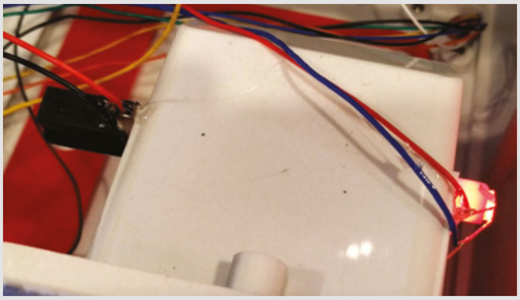
In the 1980s the arcades were where all the action was. The latest games would forcibly remove 10p coins from our pockets as we went for the highest scores. But one game was a little different; it involved a metal claw controlled by the player as they hunted for a teddy bear, watch, or some novelty toy. The claw game was great fun, but those claws were weak, and most times the teddy bear dropped back into the pile. So when we found a cheap version on eBay that offered the same fun game, but without the need for 10ps, we had to take one apart!

Made of a solid plastic frame, the chassis is robust and can be worked with hand tools and, with care, small power tools. The red and black plastics are the most robust, while the clear plastic used as windows to prizes in the candy grabber is strong but will crack if not handled gently. The unit is held together with cross-head machine screws which bite into mounting pillars in the plastic.

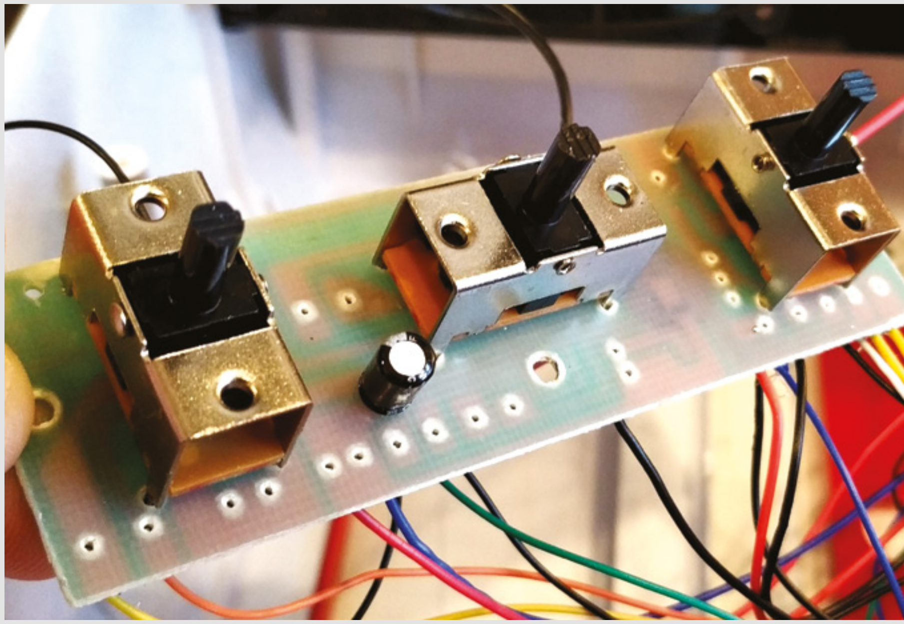
ELECTRONICS

Powered by 3 × D cell batteries, the candy grabber runs at 4.5 V throughout. This was tested at the motors and joystick controls. Rather than use batteries, the game can be modified to run from a 5 V power source – either a USB battery or a USB adapter. It should work just as well with a 5 V supply, but a DC buck converter can be used to drop the voltage down to 4.5 V with no loss of functionality.

Right
Before you fill this full of sweets, take it apart and hack it with lights and turn it into an IoT device



Above A simple light sensor and LED detect when a prize lands in the chute, triggering some 'wonderful' music to play



The grabber unit moves along a gantry system via two DC motors giving us two directions of movement, and there are limit switches along these axes, enabling the unit to stop the motors before the end is reached. To control the height of the grabber, another DC motor is used to wind a chain with the grabber hand at the bottom. When we press the joystick down, the grabber opens, and when we press up, it closes.

The controls are simple switch inputs connected to a custom single-sided board. They operate at 4.5V, which means that they can be directly used with 5V boards such as Arduino. But for Raspberry Pi and other 3.3V boards, a converter board will be required.

To start the game, a token is inserted into the slot which has a small microswitch which will trigger the game to start – signalling power to the motors, and playing a rather 'vociferous' version of carnival music. Music is provided by the same circuit board and is contained in a chip-on-board (COB) which is covered in epoxy and not available to hack. A small speaker secured to the bottom of the chassis is easy to work with and can be used with add-on boards for the Raspberry Pi to play real music.

When a player drops their prize into the chute, there is a light sensor and LED. When the prize blocks the light from the LED to the sensor, a winning jingle is played.

WEB CONTROL

We mentioned Anvil in the teardown as it is a rather clever piece of kit. Anvil is a framework that enables a user to design an application and front end for a Python project hosted directly on the web. Everything that makes up the app is in Python. It has a special library for the Raspberry Pi that enables remote control of the GPIO pins. So we can directly control the pins from a smartphone, and in turn, control the motors of the candy grabber. We can also get data from the Raspberry Pi and display it in our app. So if we are building a temperature sensor, we can send that data back to the app and create a graph using the data, in real-time. Anvil's basic tier is free and is plenty for budding IoT makers to get their teeth into.

HACKABILITY

There is so much space inside the chassis! Enough for a full Raspberry Pi and related extras. The first hack that we would do with this board is to replace the D cell batteries for a USB power supply and buck converter. The second hack would be to put a Raspberry Pi Zero W inside along with some L298D motor controllers and use the Anvil Python web framework (**anvil.works**) to build a web interface to control the grabber and play the game from our phone.

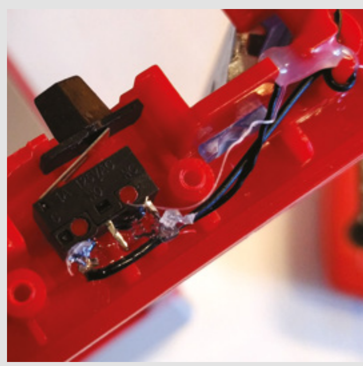
It would be great to add a few extras to this unit; for example, an Arduino could be used to power a handful of NeoPixels which would light up the game when in use.

With so much space on offer, there really is no limit to what you can do with this game!

As it comes, this is a great game to play with friends, and we can see it being used at parties in the holiday season. But the ease with which this game can be hacked with off-the-shelf components means that we can have our own internet-enabled candy grabber game and let our friends play the game from their smartphone. The simplicity of the build does not detract from how clever it is. Limit switches, motors, and gears all work well to provide a little arcade fun at home.

Above The controls for the game are simple switches operating at 4.5V, these could be hacked to work with an Arduino or Raspberry Pi

Below Limit switches prevent the motors on the gantry from moving too far. This principle is shared with 3D printers and other CNC machines



REVIEW

Bosch PBD 40 bench drill

A new take on the classic workshop staple

BOSCH £299.99 | bosch-do-it.com

By **Daniel Hollands** makerRIP

Right A compact unit with a small footprint that weighs less than 12kg

For many makers, the first power tool they purchase is a drill. It's a versatile thing, which lets you make holes, helps you screw things in, and even supports a number of other attachments (such as brush heads) to make a whole bunch of different tasks that little bit easier. Despite the popular quote that 'no one wants a drill – what they want is the hole', we're almost certain that most new makers do in fact want a drill, even if only to pretend they're James Bond for a few minutes, before using it to put up shelves (or is that just us?).

And for some, the humble power drill is enough. But for others, there comes a time when they need something a little more substantial. Maybe they need more power, holes of accurate and repeatable depth, or to make holes using larger Forstner bits than their power drill can handle. For these, a pillar drill (or drill-press) is often on the cards.

SELECTING A DRILL

Your humble reviewer was in the position of buying a pillar drill earlier in the year, looking at a number of manufacturers who all offered very similar-looking machines (almost certainly all clones of each other, with minor tweaks here and there), until he came across the Bosch PBD 40. It was clear that Bosch had reinvented the pillar drill, as their offering is different from the competition in a number of ways.

For example, anyone unfamiliar with pillar drills won't know the hassle associated with changing the speed of the drill, a process that involves removing a cover and manually adjusting one or more belts across the spindles linking the motor to the drill bit. This is vital to getting good results, as different materials and drill bit sizes require different speeds for efficient use. For example, a large-diameter Forstner bit will need to be driven more slowly to avoid burning the wood.

Left All the controls are easily accessible

The PBD 40 makes this job as simple as turning a dial on the front of the machine, letting you adjust the speed while the machine is running, something you can't do on other pillar drills. It has two gears, which are easy to switch between via a lever on the side of the unit, with the 710-watt motor supporting speeds from 200 rpm right up to 2500 rpm, and a constant electronic control system ensuring a consistent drill speed, even when used on hard materials.

Another useful feature is a millimetre-accurate read-out of drilling depth. A button lets you set the zero value (i.e. the point at which the tip of your drill bit touches the material being drilled), and the display shows how far in either direction the tip travels as it moves up and down. This is great if you know you need to drill holes to an exact depth, which you can either eyeball by watching the display, or set the built-in stop-block for the desired depth.

PRECISE MEASUREMENT

Talking of depth, the maximum distance from the baseplate to the bottom of the keyless chuck is 28 cm, which can be adjusted to a minimum of 9 cm, with the maximum travel when in use also being 9 cm. Unlike other pillar drills, the baseplate doesn't move – instead, a fixing towards the rear lets you slide the whole upper unit up and down the shaft via the wheel on the side, which is then locked off, letting you use the same wheel to depress the drill when in use.

A side effect of the baseplate not being adjustable is you're unable to change the angle. This might be a deal breaker for some, but hasn't hindered our use thus far, and should we ever require an angled hole, it should be easy enough to rig up a homemade jig to sit on the baseplate. What's lost from an adjustable baseplate is compensated for by the built-in clamp and adjustable parallel guide fence. The clamp is a little fiddly to use, but as it's attached directly to the shaft, it's sturdy, and there's no fear that you'll put it down and… darn it, where did it go?

"Unlike other pillar drills, the baseplate doesn't move – instead, a fixing towards the rear lets you **slide the whole upper unit up and down the shaft via the wheel on the side**"

Other features include an emergency stop located on the front of the unit (something sorely missing from almost every other pillar drill we looked at), a laser cross-hair to help you find centre, and a light to illuminate your working area, all of which is packed into a machine that weighs just over 11 kg, and sits inside a footprint of 33×35 cm, with a total height of 65 cm, meaning you could potentially store it away when not in use.

We're very impressed with the machine, which, despite having an official maximum drilling diameter of 40 mm in wood, was more than capable of drilling a 90 mm Forstner bit into hard oak (but always take care when pushing a machien beyond its stated limits).

VERDICT

Solid piece of kit for when a hand drill isn't quite enough.

9/10

RC2014 Micro kit

Retro computing with the RC2014 Micro

RC2014 ◆ $77 | tindie.com

By **Jo Hinchliffe** @concreted0g

The RC2014 Micro is the latest kit in a line of retro computers. Like the RC2014 Mini and the original RC2014, the Micro is a simple retro 8-bit computer system built around the venerable Z80 processor. Historically, the Z80 processor had some amazing early computer systems built around it and, while the RC2014 isn't a direct descendant of any of them, there are comparisons to be made with the ZX81 and the Apple I.

It comes well packed in an anti-static bag, with all the ICs in foam and the smaller components neatly cut off the tape reels. There is a small introductory build guide in the kit, which has some useful additions such as the colour codes for the resistors, so you don't have to work too hard to identify the different values. In the guide, there is a link to the online build instructions via the RC2014 website, which is essentially the same but larger.

Sold via RC2014's Tindie store, the Micro is the most stripped-down kit in the RC2014 range. This approach aims to keep the cost as low as possible, as it was originally designed as an option for larger volume purchases for workshops. Due to its popularity, however, RC2014 decided to release the Micro as a product in its own right. Only the essential pin headers to operate are supplied, and the ICs are all mounted directly to the PCB, not using sockets (these are optional upgrades). We really like this approach as it might be that a seasoned hardware hacker would have these parts already, but also they aren't needed for standard operation and could be added if you wanted to expand the system at a future date. Speaking of expansion, a quick tour of the RC2014 shop reveals a plethora of modules that could be added at a later date.

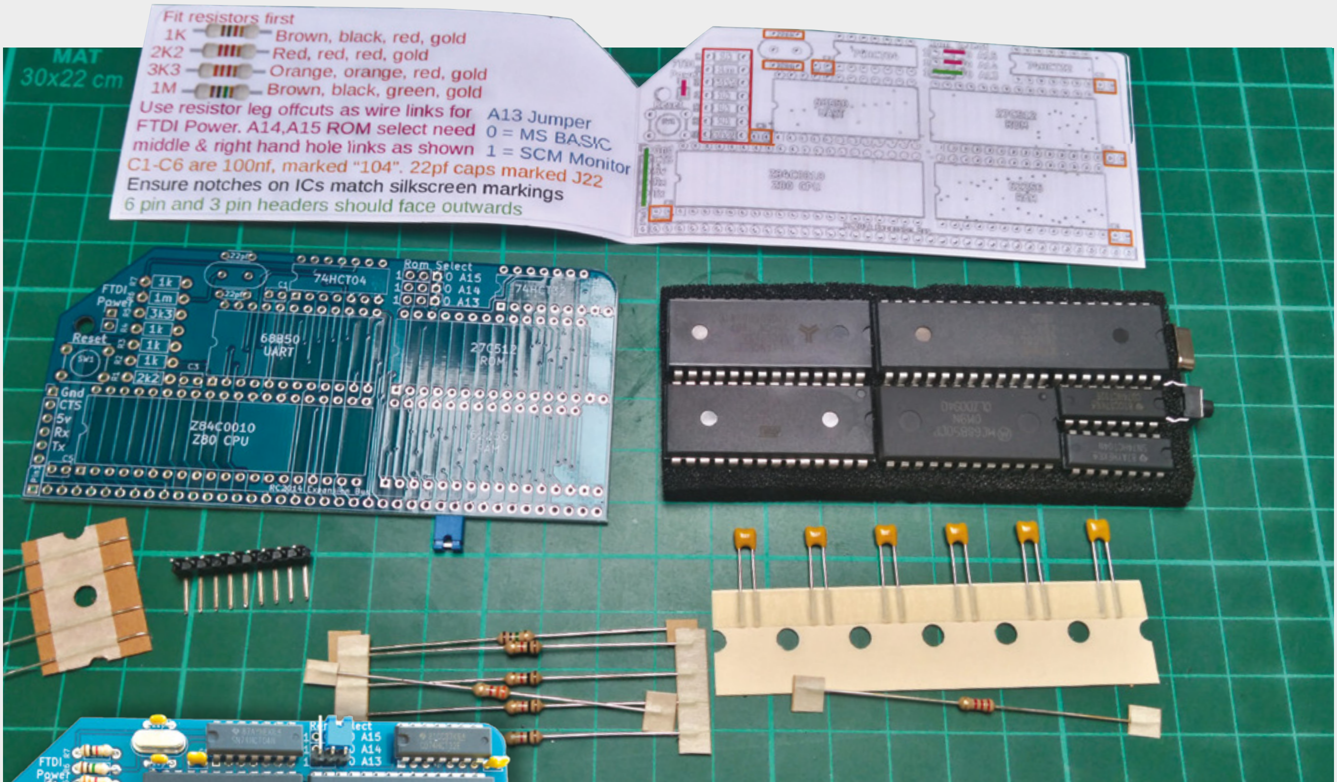
Right ◆ Expanding the RC2014 can be achieved in many ways. We spotted this amazing arcade cabinet project on the website

Credit Spencer Owen

GETTING YOURSELF TOGETHER

The kit is a joy to build – everything is well labelled on the high-quality PCB, and the board is organised really well so that there is plenty of room between components, minimising the chances of bridging any solder connections. We have soldered a fair amount, but we used a very cheap £4 USB soldering iron and some fairly large 0.8 mm solder to tackle this, as we wanted to use the type of tools a beginner might have. It was a simple build and, whilst the RC2014 site is perhaps a little nervous of recommending the kit for absolute beginners, you should be fine as long as you have a little soldering experience.

It took around an hour to solder all the components and to finish off the various jumpers between pads and get the board complete. In its current form, the RC2014 Micro will be operated from another computer with a serial connection to the RC2014



Above ◆
A fully assembled RC2014 Micro retro computer, tiny enough to slip in your pocket!

using an FTDI cable (not supplied). We realised that our budget 5V FTDI cable had a different pin configuration to the official one and so we used some male-to-female DuPont cables to create the correct connections, albeit with the classic error of wiring the RX/TX pins incorrectly the first time!

We installed PuTTY on an Ubuntu-powered laptop. PuTTY is a free SSH and Telnet client that is available for a variety of platforms, including Windows and Linux, and can be used as a serial terminal. On the configuration page of PuTTY, we indicated that we wanted a serial connection, and we set the 'serial line' window to the location of our FTDI device – in our case, this was /dev/ttyUSB0 – and we set the speed to 115200 to match the baud speed of the RC2014 Micro. We then clicked the Open button. PuTTY opens a terminal window, and we hit the reset button on the RC2014 micro, and it booted perfectly. We had set a physical header on the RC2014 Micro so that it booted into the Microsoft BASIC environment (it can boot into either Microsoft BASIC or Steve Cousins' SCM monitor ROM) and with the quick three lines of BASIC and a 'run' command, we established the RC2014 Micro was working perfectly with a classic print program.

Exploring the RC2014 website and the RC2014 Google group, we found a heap of modifications, expansions, and different projects around the RC2014 platform. The designs and expansion modules are all explained and have schematics provided, so they do provide maximum opportunity for modification and further development on the platform. If your BASIC skills are as rusty as ours, there are heaps of code examples on the RC2014 GitHub page and plenty of examples in the RC2014 Google groups community. We were also reminded that the classic Usborne books on vintage computing from the 1980s are all available as free PDF downloads. There are enough projects in those titles to keep us busy all winter. Check them out via this page: **hsmag.cc/tod2IQ**.

> " The designs and expansion modules are all **explained and have schematics provided** "

We found this kit a pleasure to build/solder, and it's a real sense of satisfaction to be able to build a fully working computer in around an hour. If you never had the chance to play with BASIC on vintage hardware, or you want to relive and explore the experience, we heartily recommend this kit. ◻

Above ◆
All the components needed to build a retro computer!

VERDICT

An enjoyable, simple, well-designed soldering kit creating a fun retro computer that fits in your hand.

10/10

The Engineering Edge

A new podcast series from Lucy Rogers

LUCY ROGERS ◈ free | **www.rs-online.com/designspark/podcasts**

By **Ben Everard** ben_everard

HackSpace magazine columnist Lucy Rogers is also available in other formats, including audio. In her new podcast *The Engineering Edge*, Lucy is looking into different applications of engineering. In episode 1, Lucy goes drone racing, and finds out how racing quadcopters are built and flown.

At the British Model Flying Association (BMFA) National Championships at RAF Barkston Heath, Lucy finds out what goes into a 500 g racing drone (that's about the same weight as a cup of tea, or this magazine), and learns what it would be like to sit in the cockpit, as she watches a race with First-Person View (FPV) goggles. The audio is recorded in the field, so it's full of the sounds and atmosphere of the event. Lucy gives a good account of what it's like to turn up to a drone race for the first time, and brings us uninitiated listeners with her. She's guided through the format by some of the racers who explain what happens, and how they built their racing drones.

"Future episodes will come out monthly, until Feb **2020, and look at other areas of engineering**"

Future episodes will come out monthly, until Feb 2020, and look at other areas of engineering. You'll find *The Engineering Edge* on iTunes, YouTube, Spotify, and all good podcasting apps.

The Engineering Edge isn't actually a new podcast, but the follow-on from *History Makers,* where Lucy, along with Bec Hill and Harriet Braine (who aren't back in the new series), looked at the past and future of various technologies such as space exploration and AI (this full series is available to download now).

Our biggest complaint with *The Engineering Edge* is the release schedule. Maybe it's just us, but a monthly release schedule makes it a little difficult to get into. We've listened, and enjoyed the first one, and now there's a full four-week wait until the next one. That does, at least, give you time to catch up on *History Makers* while you wait, if you've not listened to it before.

At 20 minutes long, *The Engineering Edge* is a short dose of engineering, perfect to punctuate your walk to work or a quick trip to the shops. Be careful though; it may make you want to build a racing drone. ◻

VERDICT

A little injection of engineering to brighten up your day.

9/10

Designing the Internet of Things

Adrian McEwen Hakim Cassimally | £19.99 | hsmag.cc/I5e3tF

By **Andrew Gregory** @AndrewGregory83

***Designing the Internet of Things,* by Adrian McEwen and Hakim Cassimally, is about more than just design.** It's about planning, prototyping, hardware, and coding for the online and the physical bits of your IoT project. It also provides the most convincing explanation of the term Internet of Things that we've ever read.

How does it fit all this into 300 pages? Well, it doesn't. The chapter on writing embedded code is a mere 18 pages, which in most textbooks would barely get you past 'hello world'. This is a good thing though: instead of giving you all the information you need to go out and start carving out your own IoT fiefdom, the book focuses instead on working through the questions you need to ask, and letting you come up with the answers unique to your own project. This approach means that the book won't date, as it would if it focused on a particular platform. It also helps the reader refine their thinking rather than trying to prescribe a 'correct' way of working. The information you need to build an IoT device is already out there; this is the information you need in order to design it.

Three rare unicorns end the book: chapters on business models, manufacturing, and ethics. Like the rest of the book, these are thoughtful, useful, and will massively help anyone thinking of building an IoT project.

VERDICT

An essential first step to refining ideas, making better choices, and building better Things.

10/10

next month

issue #26

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19 DECEMBER

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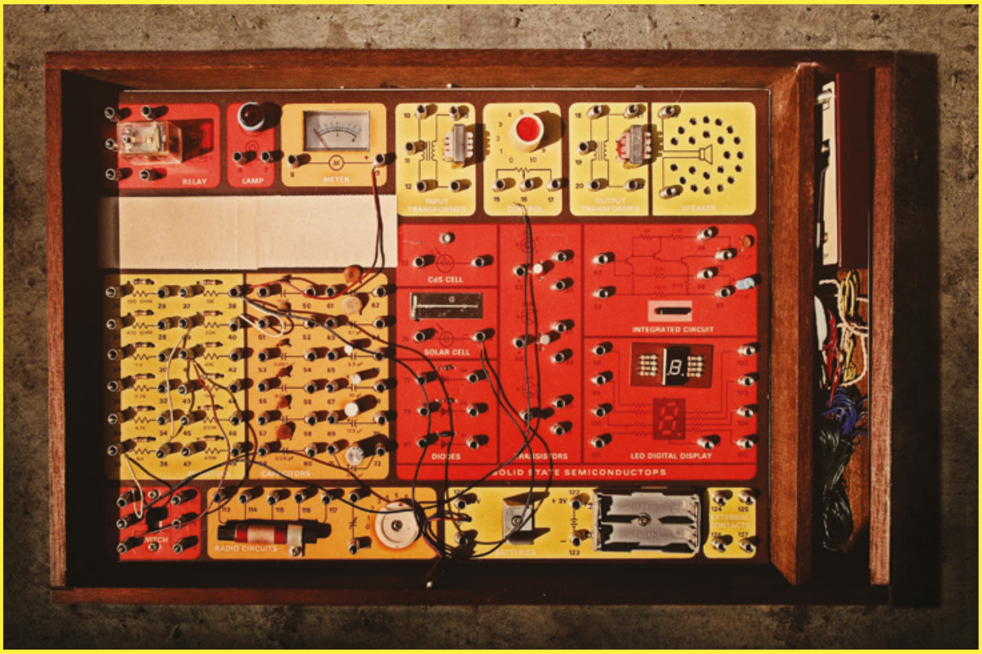

150-in-1 Electronics kit

150-in-1 (also 200-in-1, 30-in-1, and more) electronics kits introduced a generation of makers to electronics, and they're a surefire way to invoke a nostalgia hit in a room of electrical engineers. The number referred to the number of different projects you could make by wiring them up in different ways.

There were many different sets, and each had their own experiments, but radios, and oscillators were common. Today, we have far more components, kits, and tools available, but what will the engineers of tomorrow look back on with nostalgia?

Credit
Caroline (Flickr)