CAREERS

MENTORING Prizewinners inspired protégés despite tough funding environments **p.559**

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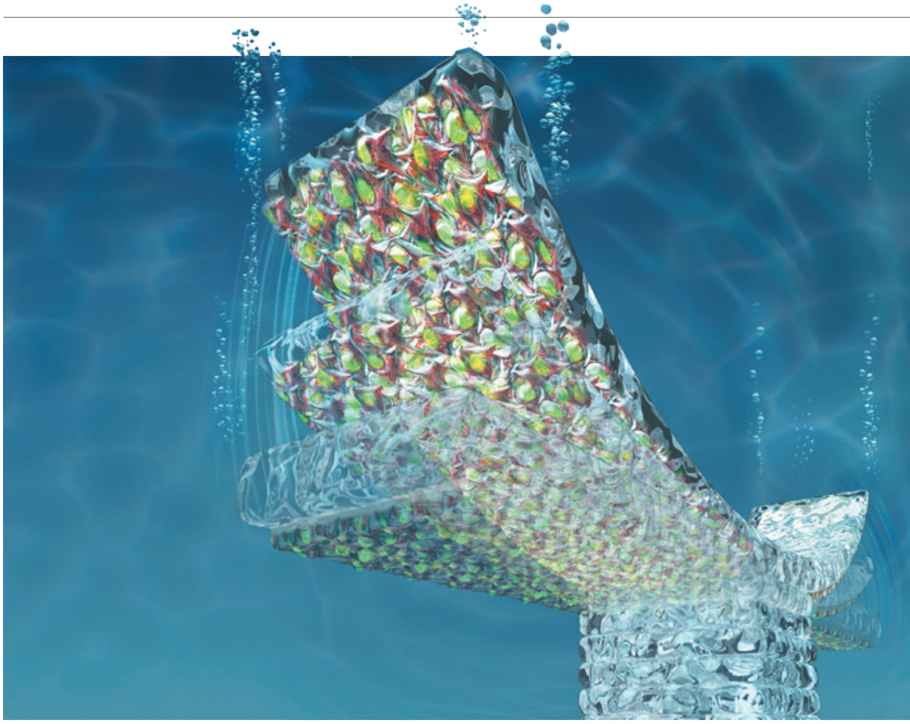


VINCENT CHAN/JANET SINN-HANLON/UNIV. ILLINOIS URBANA-CHAMPAIGN

A biobot made of printed hydrogels, cultured with rat heart cells that beat to bend a cantilever.

TECHNOLOGY

Tools from scratch

Three-dimensional printing can help researchers to design and build devices without breaking the bank.

BY NEIL SAVAGE

Nikolay Vasilyev has a bold aim: he wants to improve surgery performed inside a beating heart. Patients have fewer complications when the heart is not stopped during surgery — but manipulating surgical tools through a catheter inside a moving organ can be rather tricky.

So Vasilyev, a cardiac surgeon at Boston Children's Hospital in Massachusetts, and his colleagues developed a device they call a cardioport. The first version consisted of a white plastic tube with a clear dome on one end to push blood out of the way. Doctors could insert all sorts of surgical instruments through the short, stiff tube, and hold them in place. They could put an endoscope into the dome to image the area. Valves prevented air from leaking into the heart and blood from leaking out.

The instrument was preliminary, but impressive — especially given that it was developed by students in a medical-device class at the Massachusetts Institute of Technology (MIT) in Cambridge. More impressive still, they created the prototype using three-dimensional (3D) printing.

The hard plastic material that the printer produced is not approved for clinical use. "You probably could not use it clinically, but you could easily use it in animal experiments," says Vasilyev. So the researchers tried the device out on pig hearts before going back to the drawing board. They widened the channel of the tube to accommodate a broader variety of surgical instruments, and they placed a camera in the tip, eliminating the need for an endoscope. After going through four versions with the 3D printer, they got a university workshop to build a metal prototype. The early versions cost about US$50 apiece; the machined device cost around $10,000. Vasilyev has received a patent for the device and plans to submit it to the US Food and Drug Administration for approval.

"If we didn't have the opportunity to use the 3D printer, it would be extremely difficult to go through several iterations and come up with this final design," he says. "It's fast, easy, reproducible, cheap."

As 3D printing becomes more commonplace, the technology is enabling researchers to expand their work in new ways and to test out their ideas without breaking their budgets. "It decreases the time to failure during an experiment, which is a good thing because you can get through a lot of experiments quicker," says Adam Stokes, a microscale engineer at the University of Edinburgh, UK. "With a 3D printer you can [afford to] make lots of mistakes, and sometimes it's the mistakes that send you down interesting avenues."

Stokes started out using 3D printing to build soft robots and actuators out of a pliable polymer, creating "all kinds of strange and interesting shapes you wouldn't be able to make any other way", he says.

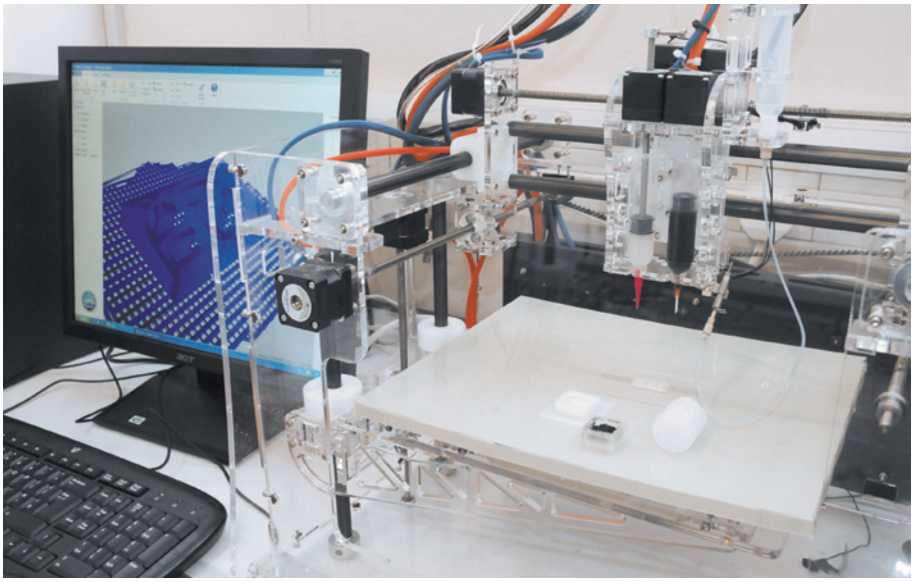
AT THE CUTTING EDGE

Three-dimensional printing, also known as additive manufacturing, creates items by building up layers of material, rather than by cutting, etching or milling to remove material, as in conventional manufacturing. This avoids some constraints of the usual methods — for example, in 3D printing, the inside of something can be shaped without the need to pass a tool into it from the outside. Certain parts can also be made as a single piece, eliminating the need for fasteners or a support structure. But there are limitations: many current machines can handle only a single material and relatively small pieces.

Printers use a variety of technologies: some use jets to build up layers of materials, such as plastics, wax or even food; in others, lasers heat a metallic powder to sinter it into a metal part. Yet others rely on resins cured by ultraviolet light or plastic selectively heated and fused. The printers can range in cost from a few hundred dollars to $2 million, depending on size, technology, level of precision and materials. Many of the cheapest come in unassembled kits. Wohler's Associates, an analyst firm in Fort Collins, Colorado, that tracks the worldwide 3D-printer market, considers $5,000 the cut-off between machines for hobbyists and those meant for professional-grade users. ▶

Hod Lipson, an engineer who runs the Creative Machines Lab at Cornell University in Ithaca, New York, draws an analogy with the history of the computer. In the 1950s, computers were rare, expensive and owned mostly by large universities and businesses, and they required expert users to perform even relatively simple tasks. By the 1970s and 1980s, personal computers had emerged, and enthusiasts were assembling them from kits and writing their own software. Now practically everyone carries a powerful computer in their pocket and can do all manner of tasks with no programming knowledge. In the case of 3D printing, Lipson says, the transition from rare, limited and cumbersome to common, versatile and easy-to-use is happening quickly.

"I used to say we're in the 1975 of printers, and now we're in the mid-80s already," he says. "We're still at the point where most people are not comfortable using 3D printers and design tools. Those who are can make things a lot easier for themselves and get an edge."



LEE CRONIN/UNIV. GLASGOW

A 3D printer can enable scientists to make specialized equipment and facilitate experiments.

MICRO MACHINES

Rashid Bashir, a nanotechnologist at the University of Illinois at Urbana-Champaign, has used 3D printing to create a series of 'biobots', each a structure with a cantilever and base a few millimetres long, made from a flexible hydrogel. Bashir coated the biobots with rat heart cells. When the heart cells beat, they cause the cantilever to bend back and forth, inching the device slowly forward. He aims one day to make versions that include sensory neurons that would sense toxic molecules in the body and direct the biobot towards the source, to trigger the release of a drug.

Bashir hopes that his research will eventually lead to a whole range of biological machines, but without 3D printing and the level of control it provides over the shape and placement of very small solid forms, it simply would not be possible. "We would not be able to fabricate the kind of structures we want to fabricate," he says.

"Most people are not comfortable using 3D printers and design tools. Those who are can make things a lot easier for themselves."
Hod Lipson

Three-dimensional printing can also make some lab technology available to researchers who otherwise cannot afford it. Lee Cronin, a chemist at the University of Glasgow, UK, uses 3D printing to build devices for running chemical reactions with precisely placed catalysts and reagents. He is also using the printer as a cheap, easily reconfigured liquid-handling robot, so that he does not have to rely on expensive, fixed systems used by pharmaceutical companies. "You can do things that are just as sophisticated but much more configurable," he says.

Cronin was introduced to 3D printing by Fab@Home, an open-source project launched by Lipson that designs self-assembly printer kits. His lab contains 12 printers — 3 complete commercial systems, 6 assembled from kits and 3 built from scratch. The open sharing of designs and ideas, along with the flexibility provided by 3D printing, could eventually make it easier to synthesize a wide range of molecules, he says.

COMMUNITY EDUCATION

The barrier to getting started in 3D printing is relatively low. Ed Tackett, an engineer who runs the National Center for Rapid Technologies at the University of California, Irvine, recommends that people who are interested in creating their own tools and devices take a college course in computer-aided-design software, such as SolidWorks, that incorporates 3D printing.

It is a good idea to check that a 3D printer is actually available and involved in the coursework before signing up for the class, says Tackett. Many US community colleges, which often train technicians for jobs in industry, offer courses in how to use the technology; GateWay Community College in Phoenix, Arizona, for instance, includes the subject in its 'Production Technology' programme. Training is also often available in hacker spaces — do-it-yourself community-based groups that allow people to tinker with design and engineering equipment (see *Nature* **499,** 509–511; 2013). A list of hacker spaces is available online at http://hackerspaces.org/wiki/.

Researchers with simple needs can upload digital designs to online services that print and ship the finished product, such as Shapeways in New York City, a spin-off of Royal Philips Electronics. Another company, Makexyz of Austin, Texas, allows users to search for local 3D-printing services — the community has participants in more than 50 countries — and request price quotes. Scientists might also consider buying and assembling their own printer for a few thousand dollars.

Neil Gershenfeld, an engineer at MIT, opened the first Fab Lab, a high-tech manufacturing workshop in which people can find help, training and equipment available for common use. Many other universities have started their own Fab Labs — Stokes, for example, plans to open one at Edinburgh next year, accompanied by an academic course — and Gershenfeld has launched the global Fab Lab Network, which lets users share designs and software and collaborate on projects too complex for any single group. Gershenfeld teaches students how to use various computer-controlled production equipment and associated software in a popular course entitled 'How to Make (Almost) Anything', a version of which is available online through MIT's OpenCourseWare programme. He will also teach a version of his course through the global Fab Lab Network in January.

Lipson says that 3D printing, like the personal computer, is an enabling tool, and that scientists should take advantage of Fab Labs and printing services. He expects use of 3D-printing labs to expand as the technology improves, control software gets better, the range of available materials grows and researchers come up with creative applications. "You have this incredible freedom to arrange material in three dimensions in any way you want," he says. "There's just 1,001 different ways to use this as a lab tool." ■

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