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David Szabo, president of Remedy Simulation Group, shows a 3-D model of a human organ based on a patient's MRI. Doctors can use the models to plan complex surgery.

3-D

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Developed in '80s

The first three-dimensional printers were developed in the 1980s to speed up prototyping, the process of creating one or two models of a proposed product to test its design and function. In 1986, a patent was issued for a "stereolithography apparatus" to Charles Hull, co-founder of 3D Systems Corp., a South Carolina company that continues to be a leader in the 3-D printing industry.

Traditional manufacturing starts with a larger piece of material and whittles it down to smaller parts. Three-dimensional printers, on the other hand, work much like inkjet printers. But instead of going back and forth with ink, 3-D printers go back and forth with a base material such as plastic or metal (or for more advanced printers, a combination of materials). A laser fuses the layers together to create a shape based on a computer-generated design. Because it adds material rather than subtracts it, the process is also known as additive manufacturing.

Early 3-D printers were designed for industrial use. The first commercially available 3-D printers hit the market around 2009; today, enthusiasts can readily find free plans online to build their own printers as well as specifications for products they can make.

"We really want them to get a machine, riff on it, upgrade it as they see fit," said Kara Sawinska, a marketing association for Aleph Objects of Colorado, maker of the LulzBot 3-D printer. "We have people who will print replacement parts for their printer, because all those files are out there. That's a cool thing to foster a lot of collaboration in the community."

Aleph, which has a distribution facility in Philadelphia, surpassed $15 million in sales last year and recently made its 1 millionth 3-D printer part. The part was, of course, created on a 3-D printer.

At a time when traditional manufacturing continues to decline, additive manufacturing has seen tremendous growth, an average of 26 percent a year over the past 27 years, according to Wohlers Associates Inc., a Colorado consulting firm that concentrates on the 3-D printing industry. Last year, the industry grew to be worth an estimated $5.165 billion worldwide, up nearly 26 percent from 2014.

"It's now getting the attention and respect it has never received in the past," said Terry Wohlers. "Major companies and brands are getting into this."

Shoe companies, hearing aid and eyeglass manufacturers and even jewelers are incorporating 3-D printing into their manufacturing processes to make pieces that are more highly customized to their wearers. Toymaker Mattel unveiled the $300 "ThingMaker" at this year's Toy Fair trade show in New York. And technology companies like HP Inc. and Canon are unveiling new 3-D printing technologies for consumer use as well.

Still, the industry is far from mature.

"3-D manufacturing isn't the silver bullet right now," said Paul Scrimale, account manager for defense contractor Parts Life Inc. in Moorestown, New Jersey. "It's another option."

Parts Life, which last year donated a MakerBot printer to Rowan College at Burlington County, began looking into 3-D printing about two years ago and quickly realized it wanted to incorporate the technology into its business making parts for military vehicles.

"You're always going to need conventional manufacturing," said Rick Pacitti, the company's vice president and general manager. But 3-D printing, he added, is "the way of the future."

Three-dimensional printing is opening new lines of business for Parts Life, Pacitti said. The company can use a 3-D scanner to scan original parts — many of which may no longer be made by the manufacturers — and then print them in stainless steel. The process cuts down lead times, as well as reduces the need for complete technical data that sometimes is missing. And, he added, it reduces the number of "non-procurable parts" by half.

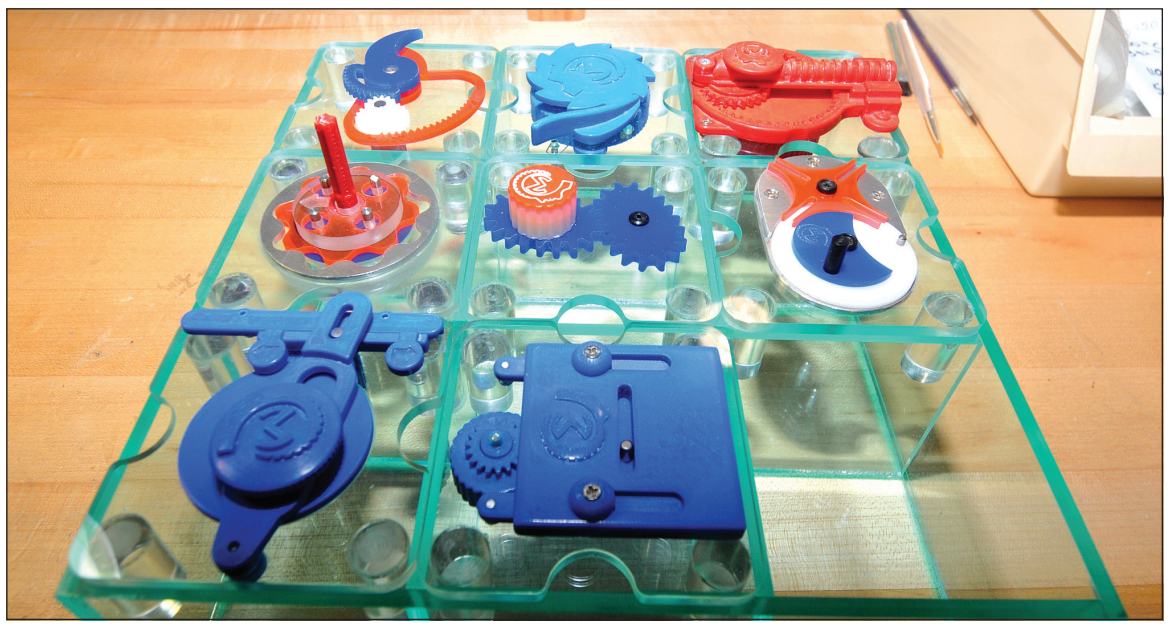
Parts Life also sees itself as a supplier of turnkey 3-D printing packages that can, for instance, provide the U.S. military with the machines, technical specifications and service to print parts on demand.

"There's plenty of places out there that will sell you equipment," Pacitti said. "There's not a company creating this turnkey package. We want to be at the forefront. We're a solutions provider. We want to be the total solution provider in the technology of 3-D printing."

At Rowan at Burlington, students in the Undergraduate Research Initiative have been using the printer to bring their ideas to life. Those recent projects include miniature rovers for NASA's Mars project, a computerized Braille system for physical objects, and physics lab kits designed for students taking classes online.

"Before this, none of the projects would be possible," said Gregory Perugini, a former Apple engineer who now leads the research initiative. "It enables them to see how real research works. And that's a skill companies want."

Three-dimensional printing isn't just turning American manufacturing on its head. It's also having a big impact in medical manufacturing.



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Some examples of work on a table at Creative Mechanisms Inc. in Warminster. The company uses three-dimensional printing technology.

Last summer, the U.S. Food and Drug Administration approved the first 3-D-printed drug product, a form of the anti-seizure medication Spritam. The drug is manufactured in East Windsor, Mercer County, by Pennsylvania drug company Aprecia, which developed a 3-D printed "ZipDose" technology that allows high-dose pills, which typically are hard to ingest because of their size, to rapidly disintegrate in the mouth.

"What we're able to do with our technology platform is accommodate high drug loads," said CEO Don Wetherhold. "Without 3DP, it would be difficult to create a fast-melt formulation. Up until this point, it wasn't feasible."

To get FDA approval, Aprecia, which is moving its manufacturing facility from New Jersey to Blue Ash, Ohio, had to prove the drug formulation remained the same throughout the 3-D printing process.

Wetherhold said he foresees the ZipDose printing process being used for other products as well.

"We envision that there are multiple products that could be brought to market in a lot of different therapeutic categories," he said. "Also in other lines of businesses, such as over-the-counter products and veterinary products. We just envisioned many, many different ways to create value to benefit patients."

Three-dimensional printing is also helping doctors better prepare for surgery by allowing them to create precise models of patient organs. Cardiologist Kevin Whitehead, head of 3-D printing program at the Children's Hospital of Philadelphia, said such models can help surgeons plan for complex surgeries.

"Sometimes, for very complex hearts, it's difficult to visualize for the surgeon how to go about (performing the surgery)," said Whitehead. "What the model allows us to do is show the surgeon the heart in a fairly similar way he might see it in the operating room, and visualize where he'd place the (surgical) patch. It's moving from 2-D images, which sometimes are adequate, but sometimes are not, to a more 3-D and physical representation of the anatomy."

CHOP develops and prints its models in-house, and is part of a clinical trial to quantify how the models help in surgical planning.

"I believe that will prove to be beneficial in these certain types of cases, allowing for better outcomes of surgery," he said. "Getting a better understanding of the heart defect will allow for better outcomes for surgery. But going beyond that, I think what we're moving toward is actually looking at doing virtual repairs and printing those out, looking at what the repair would look like and then potentially even testing out those repairs. I think we'll be able to come up with better repairs and more confidence that the proposed repair is the right strategy."

Ashley Lewis, of Gibbsboro, New Jersey, believes 3-D printing can go beyond that.

Transforming economy

"It's really transforming our economy," said Lewis, a biology and philosophy major at Rutgers University in Camden. "We, as the public, can take control over the things we're using on a day-to-day basis. You're making transplants accessible and affordable for the public. We can take products they grow in (their) backyard, and transform them into products you can transplant into a patient."

That's the research Lewis and fellow students are performing at Rutgers, using a BioBots "bioprinter" to study how to use biological materials to create structures that one day could support the development of human cells.

BioBots, the Philadelphia-based bioprinter company, is also working closely with researchers to determine what material can be used in the printers.

"They're using the devices to figure out how you build 3-D living tissues that are useful, that behave the way tissues in the body behave," BioBots' Cabrera said. "They're trying to fabricate miniature tumors. We have scientists working on building cartilage."

Scientists have already 3-D-printed liver tissue, and although much of the printed tissue is being used in pharmaceutical research, industry experts foresee using it in implanted organs, skin grafts and other procedures in the near future.

"I suspect, by the early 2020s, you're going to be able to see the first implanted 3-D-printed liver," said Steven Hausman, a technology consultant from Gaithersburg, Maryland. "They're getting prosthetic limbs, part of which can be 3-D-printed now. You can print a customized implant to replace the skull, and it shows no difference (in the natural skull. There are) customized ribs for people who have lost ribs to cancer. These things are happening now. Almost every part of the body that can be modeled can be printed."

Three-dimensional printers, Hausman said, will one day be an everyday fixture in people's homes, printing everything from household parts to food.

"It's not right around the corner, but it will happen," he said. "People are thinking about it, and they're going to want to see it in their homes. A lot of stuff in your home now, you couldn't envision 20 years ago. There were no smartphones. Everybody has a computer now, at least one, and smartphones, and GPS, and things like that. The kind of stuff we're going to be seeing in the next 20 years is going to be hard to imagine."

Said Williams: "If you think it, you can build it. We're in that shift now, where designers and engineers can think about the impossible — and they can build the impossible."

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