Engineers give a girl a hand

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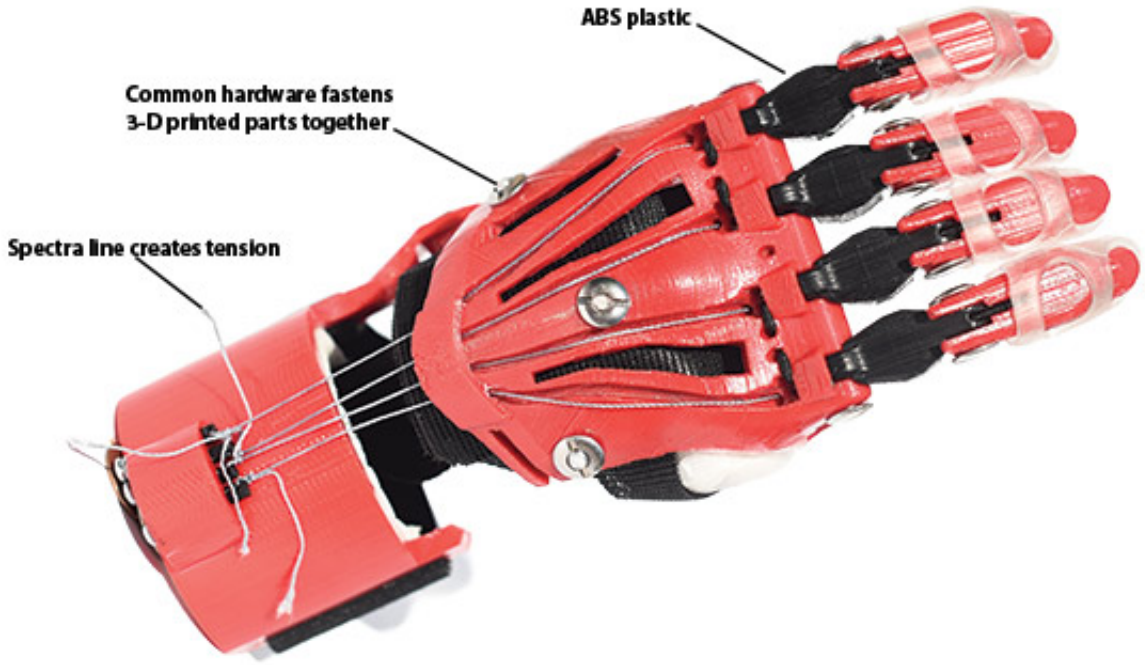

Credit: Noah Berger

Sophie is eight years old. Her favorite animal is the cheetah. Her career aspirations, in no particular order, include: singer, preschool teacher, mother, President of the United States, veterinarian, environmentalist, and photographer or videographer. Sophie also has an arch nemesis: the monkey bars.

It's not a strength issue—Sophie is strong like a gymnast (she's prone to

bust out some moves when the opportunity presents itself)—it's just that she can't grip the bars enough to keep her momentum going. Her mom, Alexa Koenig, remembers Sophie coming home from school one day last spring, her left wrist covered in bruises. When Koenig asked Sophie what she had been doing, she answered flatly: "I was trying to get all the way across on the monkey bars."

Sophie can't grip the monkey bars because she was born with a hand difference called symbrachydactyly. The four finger bones on Sophie's left hand never developed. Instead, she has a thumb and four partial fingers that hand specialists call "nubbins." The condition is caused by poor blood circulation in utero, during the window when a fetus's hand structure is developing, around six weeks. There is no way for a mother to know this is happening or to prevent it. It is estimated that, every year, 30,000 to 40,000 babies are born with some form of symbrachydactyly, which can range from minor finger anomalies to hands completely missing from the forearm down.

Sophie is adaptable and not prone to letting things slow her down, but every once in a while, learning a new skill—like riding a bike, for instance, or gripping the monkey bars—presents a new level of challenge. But with the help of a designer and an engineer working out of the CITRIS Invention Lab, where they are experimenting with 3-D printing to build low-cost, customizable prosthetics, some of Sophie's everyday challenges might just get a little bit easier.

Sophie's journey to the Invention Lab started last February after the New York Times ran a piece on the front page of the science section called "Hand of a Superhero: 3-D Printing Prosthetic Hands that are Anything but Ordinary." The story described how open-source design and 3-D printing are revolutionizing the prosthetic industry. Emerging digital manufacturing, the article explained, could allow makers to build low-cost and customizable prosthetics, on demand, for the users who need

them.

The story mentioned several boys with hand differences similar to Sophie's. Koenig saw the story and left a copy of it out on the family's kitchen table. She wanted to see if Sophie had any interest in prosthetics but not force the issue. Sophie saw the story and gravitated toward the photos of the kids playing—one of the boys is an aspiring goalkeeper for his soccer team—and she also liked the superhero spin. "In the *New York Times* story, the kids had super hands," Koenig says. "They weren't framed as a prosthetic, but as a super part." The 3-D printed hands in the story were part of an open-source project called Cyborg Beast, which was created at Creighton University in Omaha, Nebraska and is supported by NASA and others.

Koenig is the executive director of the Human Rights Center (HRC) on the Berkeley campus. Soon after she saw the Times story, she was visiting the CITRIS Invention Lab with some colleagues, getting background for a new HRC initiative that incorporates technologies into war crime investigations and prosecutions. During the tour, Koenig noticed a bank of 3-D printers along one of the lab's walls. With Cyborg Beast in mind, she asked CITRIS deputy director Camille Crittenden if she knew of any faculty or students working on prosthetics.

Soon, Invention Lab manager Chris Myers got an email from Crittenden making introductions. Myers, in turn, sent a message out to active users of the Invention Lab asking who was interested in working with Sophie.

Daniel Lim responded. Not only was he interested, but he also wanted to get working immediately. He had just completed his master's in engineering (M.Eng.) at the college's Fung Institute for Engineering Leadership. Before that, he had studied mechanical engineering in his native South Korea. In 2013, Lim came to the United States on a brief student-exchange program. That's when he learned about Berkeley. "I

got to thinking that maybe the Bay Area is best for me. When I returned home, I made the Campanile my screen saver." When it came time to apply to graduate school, the decision was easy. "It was like a dream coming true," he says.

Lim's student-exchange trip also exposed him to 3-D printing. While in the United States, one of his friends bought a 3-D printer on Kickstarter, the crowdfunding site. He was blown away by both crowdfunding and 3-D printing. When he got back to South Korea, he says, he wanted to continue working with 3-D printing, but couldn't find a suitable machine, so he wound up building one. "It was horrible," in comparison to some of today's off-the-shelf printers, he says, "but at least you could make out the shape of what I was printing."

After completing the M.Eng. program, Lim decided to stay in the United States. When he got the email from Myers, he thought that the project sounded like the perfect use of his skill set. "I studied engineering for the past five years, and I thought this is the first project where I can directly improve someone's life," Lim says. "When I saw Sophie's picture, I wanted to do this."

Lim and Myers met with Sophie and Alexa, as well as Sophie's 10-year-old brother, Zander, and father, Don, at the beginning of June in the Invention Lab. During the first meeting, they took measurements of Sophie's hand and talked about modifying the Cyborg Beast files for the best fit. The parts are printed from ABS plastic (the same material as Legos) and put together with some straightforward hardware, meaning each prototype costs less than $10 to make. Lim and Myers modified the thumb on the design files because the stock prosthetic template has a thumb, which Sophie does not need.

In the months since the *New York Times* piece appeared, there have been other high-profile articles in the media challenging the notion that a

democratized open-source prosthetic movement is a good idea. Prosthetics are a specialized tool, designed, built and fitted by experts. Building them in garages, basements and makers spaces, critics argue, could endanger the safety of end users.

Proponents of the open-source prosthetic movement say that some technologies developed in the 15th and 16th century—such as the opposing-hook prosthetic hand that is attached and operated using a series of tensioning straps—are still used in contemporary prosthetic design. "Existing prosthetics are very archaic," Lim says.

Myers is somewhere in the middle. He thinks that existing prosthetics need an update and that they cost too much—estimates vary, but customized prosthetics can range from $5,000 to $40,000. But he is also quick to manage expectations about the strength, durability and limited functionality of a prosthetic downloaded from the Internet and printed on a 3-D printer. At one point, when Sophie was trying the first prototype that he and Lim built, Myers said, "This might break in a day."

Nevertheless, during the second meeting, and after some adjustments, Sophie tries her new super hand, which was printed in red and black ABS (like Iron Man, Lim says). After a few attempts, she is able to clench the fingers closed. They open and close depending on the amount of tension Sophie puts on them when she curls or releases her wrist. The wrist curl contracts thin Spectra line, a type of thread that is stronger than carbon fiber and favored by offshore fishermen for its durability and lack of stretch.

Myers adjusts the tiny cables so that the fingers work in unison. The fingers all pivot on a single bolt that threads through their base, like a straight-lined knuckle; he repositions the device so that it aligns better with the wrist.

Sophie puts it back on and is tentatively flexing and relaxing it. She picks up a plastic tube, the width of a fat magic marker, with her super hand and passes it to her dad, he passes it back to her, and she is able to grab it. It's impressive, and everyone breathes a sigh of relief—the hand actually works.

Zander speaks up first. "I see a flaw in this plan," he says. "You won't be able to use chopsticks."

"And," he goes on. "The strings are too long. Sophie, can you poke dad?"

"Zander, do you see anything positive about this?" Lim asks him jokingly.

Credit: Adriel Olmos

"Yeah," Zander says, looking at Sophie, "now you have another hand."

Two weeks later Sophie and her family are back in the Invention Lab.

Myers and Lim are eager to hear how the modified super hand held up. Sophie took it with her to Winning Hands camp, which is put on by Shriners Hospitals for kids with hand differences. Koenig asks Sophie if she tried the monkey bars at camp. Myers cringes.

"Yeah," Sophie says, "I slipped off."

But, Koenig says, "Sophie did manage a few cartwheels when we were leaving last time."

Myers prepares to cast Sophie's hand in resin so that he and Lim can continue modifying future versions of her prosthetic without her having to come to the lab each time. Lim found some old Tom and Jerry cartoons on YouTube for Sophie to watch while the resin cures. Myers asks Sophie questions about how she is using the hand.

Sophie shows her family how the super hand works.

"If she gets to help design it, then it's hers and she'll have a sense of ownership, and it won't just be a fancy version of a store-bought version that we made in the lab," Myers says. 'I'm a big proponent of getting kids involved with technology at a young age, so they can know more about how their world works."

Myers and Lim both consider this an ongoing project. "Right now it's a simple mechanism for gripping something," Lim says, and then, starting to brainstorm out loud, "In the next version, I want to put sensors in it and try to make it more intuitive. One of the first things we can do is make it more aesthetically pleasing and improve the user experience."

Lim spent some of his time over the summer reading journal articles about prosthetics. He's thinking about building his Ph.D. research around low-cost prosthetic design. He also thinks a lot about how to make Sophie's hand better.

"In the end," he says, "we want Sophie to be able to do the monkey bars."

Provided by University of California - Berkeley