Living Machines Go Wild

Policing the Imaginative Horizons of Synthetic Biology

Eben Kirksey

Every year thousands of young people exhibit designs for genetically modified organisms at the International Genetically Engineered Machine (iGEM) competition in Boston. Regarding living creatures as "machines" is nothing new. Even still, life is being remade in novel and surprising ways as iGEM students use increasingly fast and cheap genetic engineering tools. Designs for living machines that seek to optimize biology are ironically generating new kinds of wildness where a loss of control presents unknown risks and new dangers. Human health and the well-being of other species is at stake. Following students from iGEM to their home universities—in Sydney, London, and Abu Dhabi—I studied the interplay of utopian dreams and nightmare scenarios. Some iGEM participants hope to alter the human condition with new kinds of symbiotic bacteria. Other competitors seek to repair fragile multispecies worlds where endangered species and structurally marginalized people are in precarious situations. Power is functioning predictably at iGEM. FBI agents are promoting government and corporate interests as they police narrowly defined risks. Gatekeepers to capital are translating the entrepreneurial potential of student projects into profit. The imagination has become a battlefield as students with alternative priorities, values, interests, and ethical commitments struggle to find support.

A massive science fair in Boston—the International Genetically Engineered Machine (iGEM) competition—gathers together thousands of ambitious high school and university students every October for a Giant Jamboree. In 2016 students from Copenhagen made space moss to colonize Mars, while the team from Singapore engineered microbes to become controlled missiles targeting tumor cells. Students from Sydney, Australia, tried to create photosynthetic skin cells capable of harnessing energy from the sun, while another group from London aimed to increase our collective happiness—by hacking the gut microbiome.

Regarding organisms as "machines" to be redesigned and engineered is nothing new. In 1952 Georges Canguilhem noted that "the organism has been explained on the basis of a preconceived idea of the structure and functioning of the machine; but only rarely have the structure and function of the organism been used to make the construction of the machine itself more understandable" (Canguilhem 1991:45). Since Canguilhem's times, dominant trends have been upended. Machine tools of molecular biology are increasingly modeled after organisms. But as scientists try to apply engineering principles to life itself, mechanical rules are breaking down. Life is running wild.

Most students who compete in iGEM aim to build new living machines with BioBricks—standard biological parts likened to plastic LEGO bricks. With these cheap plug-and-play tools they aim to transform "biology into a fully standardized and abstracted engineering discipline understood in a literal sense on the *analogy* of electrical and computer engineering" (Rabinow and Bennett 2012:67). Five teams from elite US universities attended the first iGEM competition in 2004 and helped launch a new scientific discipline: synthetic biology. Since then, the competition has grown exponentially. It is open to entrepreneurial students from anywhere in the world who can come up with the $4,500 team registration fee, plus travel expenses.

I engaged with the speculative aspirations of diverse iGEM projects at the 2016 Giant Jamboree, asking basic questions that speak back to concerns of cultural anthropology: How are political and economic forces shaping the imaginative horizons of biotechnologists? Can synthetic forms of life be stabilized in new symbiotic relationships? What are the limits of our own imagination, as anthropologists join with technologists in speculating about the promise and perils of emergent forms of life? Deploying the methods of multi-sited ethnography, I pursued these questions as I "followed the people" (Marcus 1995)—from the Hynes Convention Center in Boston to university laboratories in Sydney, London, and Abu Dhabi.

The Imagination Is a Battlefield

Blue and orange lights washed over student teams as they found their seats in the main auditorium of the convention center. Randy Rettberg, the president and founder of the iGEM competition, officiated in a signature white hoodie. Stepping up to the microphone, Rettberg welcomed some 5,600 students to the 2016 Giant Jamboree, celebrating the multitude of new synthetic organisms that they had brought to life. His language was promissory, mixing science with speculation, dreams of capital accumulation with hope and hype (cf. Fortun 2001:146). Rettberg said, "Companies are starting and growing, investors are

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investing, governments are funding, universities are expanding their programs, journalists are reporting, and communities are asking, 'Where will this take us?'" The imaginative horizons of the iGEM event were being shaped by the values of the global innovation economy. Optimism about the next generation of passionate dreamers, who can change the world, radiated from the main stage (cf. Irani 2019:1).

The unbridled enthusiasm of Rettberg gave way to dramatic theatrics that heralded the arrival of FBI agents. Visions of a techno-utopia were suddenly juxtaposed with nightmares of bioterrorism. The FBI had pride of place in the program with a special keynote address. It was the night before Halloween and Special Agent Josh Cantor assumed the stage while a clip from Aerosmith played with lights flashing purple and pink. He was bearded, with big glasses, and wore a skully hipster hat pulled tight over his head. Cantor said, "We want to change the way you guys think." Fueling the excitement of the aspiring technologists in the audience, he proclaimed, "There are solutions in this room to almost any problem we face." Cantor handed the stage over to Ed You, a bald Asian American official from the Weapons of Mass Destruction Directorate, saying he is "a rock star in the field" (fig. 1).

After zipping through PowerPoint slides of FBI agents from popular culture—Muller and Scully from *X-Files*, Agent Smith from the *Matrix*—You showed pictures of bad guys. A neo-Nazi sympathizer was being led away in handcuffs for buying three vials of plague bacteria. Another guy, pictured in an orange prison jumpsuit, had ordered some TTX poison—allegedly in a plot to kill his wife. These particular bad guys had not yet committed any acts of bioterrorism, but their patterns of shopping and searching the Internet indicated that they were imagining a nefarious plot.

A logo from the Global War on Terror—an eagle clutching symbols for nuclear radiation, dangerous chemicals, biohazards with an American flag unfurling in the background—was emblazoned on the slides. "One thing that I want to really focus on is threats," said You, as some students became visibly uncomfortable. "What do I mean by threat?" he asked while showing a slide listing "biological crimes" and weapons crimes. "If you are in possession of a biological material and you use it as a weapon, you are in violation of this law and the FBI will investigate you."

An earlier ethnographic study of FBI operations in the biological sciences concluded that "the border between suspect and expert is not given in advance" (Tocchetti and Aguiton 2015:828). While policing the imaginative horizons of scientists "the FBI ends up securing a techno-libertarian utopia and the promise of economic wealth" (846).

With his 2016 iGEM keynote address, Special Agent You offered his own vision of a promising future—where advances in genetic technologies and surveillance regimes would open up new opportunities for capital markets. With a disarming gesture, he showed a picture of Pigpen, from the Charlie Brown cartoon series, telling the students, "This guy is you—and I don't mean you need to take a shower." An image of the DNA double helix popped up on the screen alongside icons from

Figure 1. Students gather for the iGEM Giant Jamboree in 2016, in Boston. Photograph by Eben Kirksey.

Facebook, Instagram, and Twitter above the cloud of dirt surrounding Pigpen. "What I'm talking about is wherever you go, you leave a little bit of yourself. You leave DNA everywhere" (fig. 2).

Information is being collected today—geotagged social media data and medical records, according to You—that will be integrated in the near future to deliver precision targeted therapies. "There are billions and billions of dollars internationally being invested in this future, which is great," he added. Lucrative returns are on the horizon, he intimated, for people who can develop new streams of biological data into profitable applications. "But guess what?" he added. "The bad guys know this too. As of today, your biological data is worth more than your credit card information. They know, and they're trying to get it."

While the "bad guy" trope was loosely bandied about in Special Agent You's presentation, I remained mindful of the long history of FBI operations where the distinction between legitimate and illegitimate partners, gangsters and corporations, informants and criminals has been difficult to discern (see, i.e., Davis 1974). While You made it seem like his team was simply promoting legitimate uses of biotechnology, the FBI was busy investigating Chinese-American scientists—accusing them of stealing biomedical research secrets. The *New York Times* reported that the FBI has launched over 180 biotech investigations where the primary targets were "scientists of Chinese descent, including naturalized American citizens." The *Times* reports that they were pursuing scientists with access to ideas, designs, data, and methods that could produce profitable new medical treatments or biotechnology applications (Kolata 2019).

The FBI was at iGEM to recruit new special agents, with a table at the career fair. They were also there to win hearts and minds. Special Agent You encouraged everyone in the room to report suspicious activities of friends or fellow students by calling his team at the FBI Weapons of Mass Destruction Directorate or local law enforcement officers. He said that the FBI was not there "looking at the risk of what you do" at the iGEM Jamboree. "It's about how do we protect you, your work, your person, your schools, your businesses," he said. "That's why we do outreach." By the end of the presentation, it still was not exactly clear how the special agents wanted to change the ways the students were thinking. But the FBI did make one clear point: they were policing the future of biotechnology.

"The imagination is a battlefield," according to Ruha Benjamin. She argues that some imagined futures are already getting closer to reality as technologists battle to gain support for new ideas, while other visions are scuttled if they do not align with dominant political and economic forces. "We should acknowledge that many people are forced to live inside someone else's imagination," Benjamin said in a recent lecture. "Some inventions appear inevitable and desirable," she continued,

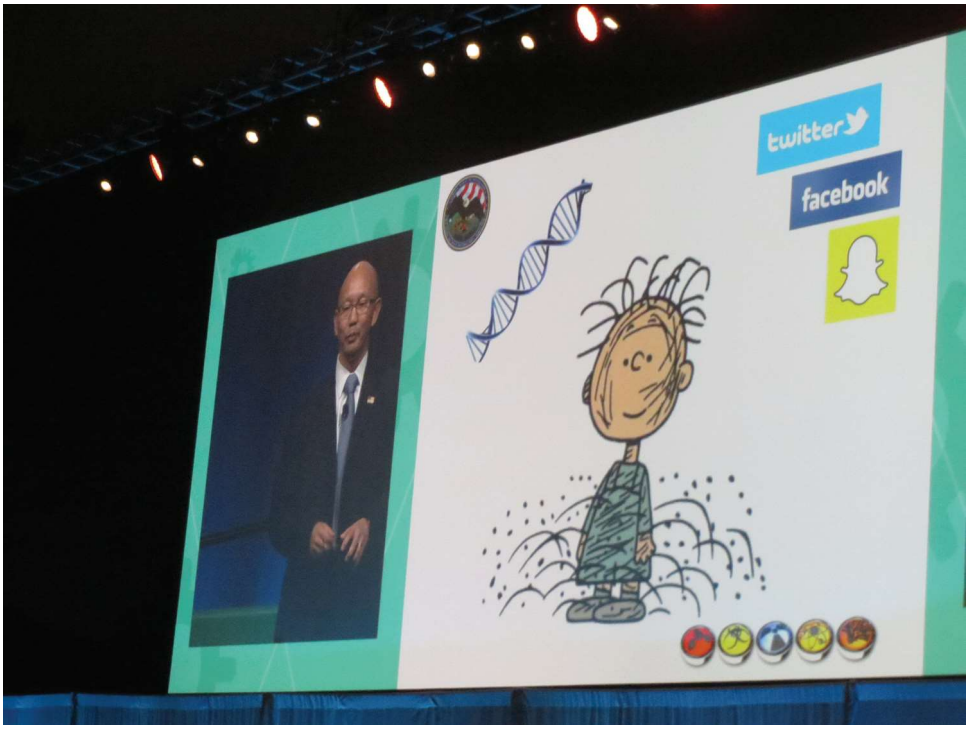

Figure 2. Similarly to the way Pigpen leaves traces of his presence behind, traces of DNA and digital information are constantly left behind by each of us, according to FBI Special Agent Ed You. Photograph by Eben Kirksey.

because the value of innovation remains unquestioned. "The nightmares that many people are forced to endure are the underside of elite fantasies about efficiency and profit."[1]

After the FBI finished talking about their particular visions of imaginary battlefields, a self-styled "thought leader"—John Cumbers, from a company called Synbiobeta—assumed the stage. While the FBI was quietly investigating Asian-American scientists, Cumbers was breathless with enthusiasm about developments in China, celebrating a fresh influx of government funds into the field. "I just got off the plane from Shanghai this morning, and what is happening in China is the most exciting thing that I've seen," he said. "They are investing over $2 billion in synthetic biology over the next five years."

Government funding in the United States was falling behind China, Cumbers lamented, but private US companies had made investments in synthetic biology exceeding $1 billion in 2016. "We have been doing education in Silicon Valley," Cumbers said, "to turn tech investors into biotech investors." Cumbers showed a slide with pictures of Bill Gates and other big Silicon Valley entrepreneurs like Peter Thiel who helped bring us PayPal and Facebook. "The founders of these companies are starting to place bets on the biotech industry," he reported.

Synbiobeta, the start-up incubator and accelerator led by Cumbers, was offering to give students up to $120,000 to found their own start-ups. At iGEM he was searching for new ideas and future entrepreneurs. Cumbers made it seem like the students were early insiders in a new movement. But biotech investors and entrepreneurs who joined the "revolution" at a much earlier moment—in the 1980s—were left holding worthless shares when start-up companies failed to recover massive costs of research and development (Yoxen 1984:11).

"Put your hand up if you are thinking of starting a company in the next five years," he instructed, noting that there were about 50 hands. Hundreds of new hands shot up when he invited the students to imagine further into the future: "Put your hand up if you are thinking of starting a company in the next ten years."

"Put your hand up if you think that you'll never start a company," he ordered. I sheepishly raised my hand, standing out as part of a small minority in a sea filled with thousands of budding scientists. "That's about 20% or 30%," he observed. "Okay. I'm just future-proofing our business."

Cumbers was recruiting students into the mobile class of elite cosmopolitan innovators with the promises of open-ended speculation (cf. Irani 2019). Biotechnologists have been moving away from production and direct productivity for more than two decades and "toward knowledge, technologies of life, and promise" (Thompson 2005:258). Students were being drawn toward this dreamworld—an imagined future where they could join the team of good guys in bringing health, prosperity, and well-being to the planet.

1. Ruha Benjamin, 2019, Race after technology, Databite no. 124. https://www.youtube.com/watch?v=zZEVAVf6_Ak.

After the opening iGEM ceremonies, I followed the students, thought leaders, and FBI agents out into the hallways of the convention center. I studied the contours of imagined futures that were getting closer to reality as aspiring scientists competed to gain support and recognition for their ideas and values. People like You and Cumbers were shaping the contours of promissory futures in this experimental space. These powerful gatekeepers were deciding which imagined futures were realistic—and merited support—and which were potentially dangerous to the social, political, and moral order (cf. Hurlbut 2016).

Reality blurred as I wandered around the convention center, talking with young dreamers who stood in front of posters that illustrated a dizzying array of scientific facts and speculative fictions. Some told me about living organisms that they had actually created, while others played fast-and-loose with reality. It would be easy to dismiss the students who flock to iGEM for harboring a comic faith in technofixes. Donna Haraway has described a widespread secular conviction that was enthusiastically embraced by many participants in the Giant Jamboree: "Technology will somehow come to the rescue of its naughty but very clever children" (Haraway 2016:3). It certainly is ironic that cutting-edge biotechnology is seen as a solution to many unanticipated problems that emerged from the modern technology of yesteryear. Even still, some of the projects had the potential to remake (or disrupt) the known world. While walking around the convention center, I took inventory of the diverse articulations of biotechnology, ethics, politics, and capitalism, even while remaining skeptical of claims about the power of genetic technologies (cf. Kirksey 2020:5).

Even as iGEM participants engaged in wild speculation about technofixes, the posters on display diagnosed a multitude of real-world problems (cf. Stengers 2011:347). Bats were dying from white-nose disease. Honey bees were in decline as pesticides, pathogenic mites, and viruses interacted in agro-industrial ecosystems. Coral reefs were bleaching. Nuclear radiation was leaking from power plants in Europe, Asia, and the United States. Legions of people were dying from cancers. Mercury was polluting river water in the Amazon, the oceans were teeming with plastic, antibiotics were flowing into rivers from farms and human sewage in China. Students aspired to address this motley array of problems with their iGEM projects and even to accomplish more lofty goals—like solving world hunger. But most of the imagined solutions to these problems were remarkably similar: what we need is new genetically modified organisms.

When I caught up with Cumbers, the thought leader from Synbiobeta, applause, hoots, and whistles erupted in the background—a team from China was celebrating their achievements, as a camera crew walked by. I asked him about the latest biotechnology projects that were attracting industry funding. Modern Meadows had just raised funds to create synthetic bioleather, he said. Biofabrication companies were aspiring to disrupt many different fields—from fashion, to furniture, to automobiles—with the next generation of fabrics printed with living

materials. New GMO foods and bioengineered flavors were also in the pipeline. Scientific foundries, like Gingko Bioworks, were trying to replace traditional cosmetics and skin care products with probiotic synthetic bacteria.

As I talked with Cumbers, he made it clear that Synbiobeta was a profit-driven enterprise rather than a venture driven by environmental or humanitarian values. Drawing him into a multispecies frame of reference, I asked if he was supporting any projects that promised to benefit other organisms. Students from the University of Missouri were trying to create probiotic medicine for endangered bats. I had just read their poster that explained that a disease, the white-nose fungus, was driving many bat species to the brink of extinction. The students were trying to design a synthetic microbe to produce an antifungal chemical. After giving Cumbers background about this project, I asked, "Will any of your investors prioritize these kinds of things?" He countered with a rhetorical question, mixing up the disease with the identity of endangered animals: "Who is benefiting from white nosed bats? The bats are not going to pay for anything. You will never see industry pay for that."

Cumbers was looking for the next generation of young iGEM entrepreneurs who could generate returns on capital invested in the biological sciences. He did not see any lucrative opportunities in this applied conservation project. Later I learned that technical stumbling blocks and lack of funding meant that the students from Missouri who cared for bats were unable to get their idea off of the ground.

Cumbers pointed me to other projects that were already generating revenue—illustrating that seemingly elusive promises about emergent technologies could be brought back into the realm of productivity and profit. "Pharmaceuticals are an important part of the ecosystem," he said, "as are biobased chemicals, automation systems, and biofuels." As Cumbers ducked away, I wandered toward a table where a team from the FBI was gathered—to see if I could learn more about the political and economic forces that were shaping the imaginative horizons of biotechnology (cf. Crapanzano 2004).

Into the Wild

The FBI agents were handing out Safeguarding Science cards with vivid cartoon graphics of lethal microbes. Icons—showing skulls, pills, test tubes, and bugs—illustrated the type, status, transmission, and treatment of the various diseases. The card for *Yersinia pestis* (plague) indicated the maximum level for lethality and contagiousness. Plague (aka black death) "is highly contagious and infects both humans and animals," reported the card. It is transmitted primarily by flea bites, "but also through eating infected meat, or through the inhalation of infectious respiratory droplets."

The FBI was looking for a limited set of hazards at iGEM. Destructive military applications of biotechnology were top priority. There were protocols in place to mitigate risks to human health and agriculture, they claimed. Student projects at iGEM were being checked against a database of DNA sequences derived from the US Federal Select Agent List. Human diseases—like anthrax and cholera—were the primary nonhuman agents of interest. Some agricultural pests—like avian influenza or foot and mouth disease—were also included. The screening process was designed to flag unintentional uses of potentially harmful DNA sequences by students without proper permissions as well as the deliberate use of this genetic information by the "bad guys."

Students from the University of New South Wales (UNSW) in Sydney, my own campus at the time, had been working with genes from one of the deadly microbes on the Safeguarding Science cards, in a particularly risky and imaginative project. Visions of creating green people, capable of harnessing energy directly from the sun, led the UNSW iGEM team to work with genes from plague (*Yersinia pestis*) and other bugs responsible for food poisoning. The students were working in a laboratory on the other side of campus from my office, under the supervision of a molecular biology professor. I first learned about this venture when the students asked to interview me, as a faculty member in the Environmental Humanities program, about the social, ethical, and legal implications of their experiment.

I was amused and more than a little alarmed when one of the students—a guy with blonde hair and blue eyes whom I will call Mark—explained that he wanted to create a synthetic microbe that could selectively invade the human body, proliferate within the skin, and then perform photosynthesis, converting light into food. Symbiosis with cyanobacteria, a single-celled organism that lives in water and makes its own food from light, "could be an elegant solution to world hunger," he said. Plants are thought to have acquired photosynthesis by gradually incorporating microbes in their tissues (Margulis and Sagan 2002). "It has happened before," Mark said. "It only took 64 million years; why don't we give it a shot in eight months?"

As I talked with Mark and other students, my own ideas were drawn into a rhetorical loop (cf. Roosth 2013:156). My own questions and concerns were fed back to me. After our initial chat, they sent me follow-up questions: "What is the importance of imagination to the development of synthetic biology tools? What external influences exist which limit/mediate the imaginative process? Who gets to do the imagining and who gets to do the science?"

Mark told me about the steps his team had taken as they tried to bring symbiotic dreams closer to reality. When they browsed through iGEM's collection of BioBricks they spotted a project that might help them create photosynthetic people.

An earlier iGEM team from Warsaw, Poland, had created synthetic microbes with the capacity to infect human cells. The Polish students had tried to develop a tiny living machine that would invade human tissues to deliver a diverse array of drugs or proteins. They took DNA from plague and *Listeria monocytogenes*, a bug that causes food poisoning, and created a new synthetic strain of bacteria. When their gene sequences were run through the US Federal Select Agent database, they sent up

a red flag. But since the students apparently had all the proper paperwork in place, iGEM let them proceed.

Rather than manufacture a predictable machine, the Polish students had created a new form of life with unknown risks and dangers (cf. Franklin 2003:102). The very properties that make plague and *Listeria* harmful made them potentially useful to the student bioengineers. A toxic protein called "invasin" helps plague bacteria invade the human body: it prompts human cells to surround and envelop the microbe. *Listeria* uses a pore-forming toxin to get inside host cells. The Warsaw team succeeded in creating a synthetic microbe that infected human cells 38.96% of the time in experimental trials. One of the students joked on the iGEM website that they inadvertently made "a good bioweapon by allowing bacteria to enter and live inside human cells."[2]

When the Polish students deposited this BioBrick in the iGEM archive, it was labeled as potentially dangerous with a funny and cryptic note, "Experience: Works. Sample: It's complicated." When the students from UNSW Sydney decided to order it, they had to submit a safety "Check-In." After filling out some on-line forms, the Australian students ordered the BioBrick with relative ease. They settled in to wait for their special delivery from iGEM headquarters.

Back in Boston a message popped up on Vinoo Selvarajah's computer terminal, signaling that the UNSW Sydney team wanted some potentially dangerous materials. As the director of the iGEM Registry, Selvarajah was responsible for curating a collection of over 20,000 BioBricks from students and bioengineers around the world. Selvarajah was scrambling, along with his team of interns, to get hundreds of packages out the door to teams registered for the annual competition (fig. 3).

After Selvarajah checked the paperwork from the UNSW students, he walked down the hall to an industrial freezer that housed these BioBricks along with thousands of other samples. The biological parts were being stored inside microorganisms—in this case *Escherichia coli* bacteria—rather than as isolated fragments of DNA. Selvarajah cut off a piece of gel from the petri dish housing the synthetic critters from Warsaw and popped it in a tube. Then the microbes went out with the mail on an international journey to Australia.

When the students opened the box in Sydney, they were shocked. They had been expecting a shipment of purified DNA for insertion into their green cyanobacteria. Instead of a sterile vial with isolated molecules, the students received infectious synthetic bacteria. The students wrote up a safety report, noting with alarm that iGEM sent them live microbes that violated the rules at UNSW Sydney. The students killed the bugs and sent off the report to iGEM, and tweeted about it for all the world to see. But they never received a response.

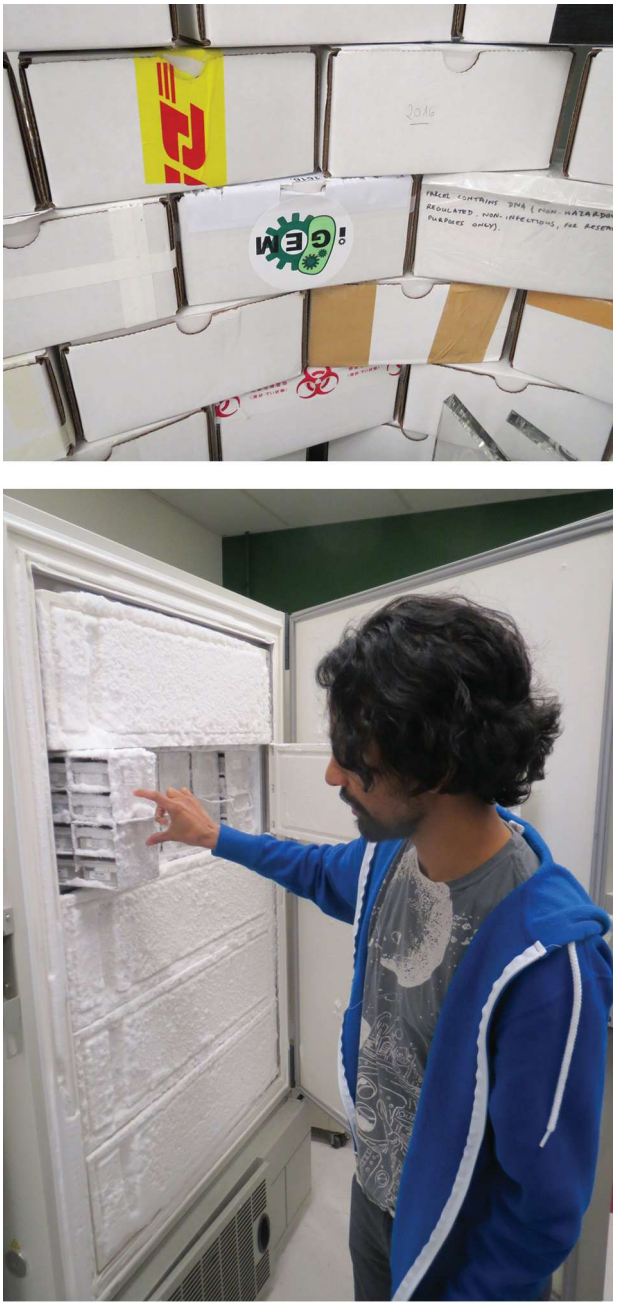

Figure 3. Every year students submit new biological parts, or BioBricks, by mail to the iGEM headquarters in Boston. The biological parts arrive in parcels (*top*), are stored in a freezer (*bottom*), and then redistributed as orders come in. Photographs by Eben Kirksey.

Ultimately the UNSW Sydney students were not able to create green people or even get cyanobacteria to invade human cells. "It is not easy to do these things," Mark said. "It is actually hard to do anything. So you don't actually have to worry about projects at that level ruining the world." Along the way they also discovered that some claims by the FBI checked out: the special agents were not "looking at the risk" of student projects at the Giant Jamboree.

2. Michael Lower, 2017, Part:BBa_K177029. http://parts.igem.org/Part:BBa_K177029 (accessed February 23, 2021).

Mind the Gut

The University College London iGEM team hoped to enhance people with symbiotic microbes that would theoretically make people happier. They took a human gene, a string of DNA from a published scientific paper, and inserted it into living bacteria. A young woman whom I call Rose simply typed genetic code into a standard template to create a synthetic gene. After copying and pasting this code into a biotech website, she ordered her construct with a credit card. When a package arrived with the artificial gene a few days later, Rose mixed it together with live bacteria in a tube of liquid. Then she zapped the concoction with a contraption called an electroporator. "And, yeah," she told me, "the bacteria basically took it up."

Rose and her friends were inspired by the research of Cryan, a microbiologist known for his work on the gut-brain axis. A popular book written by Cryan and colleagues opens with a provocative question: "Are bacteria controlling your brain?" The book argues that "microbes can actually commandeer your mind, control your tastes, and alter your moods" (Anderson, Cryan, and Dinan 2017:9). Biologists exploring the gut-brain axis are studying how conditions like depression, anxiety, and autism might be linked to the dynamics of microbial communities in our intestines.

When Rose traveled to University College Cork in Ireland to meet Cryan, the established scientist tried to discourage her from conducting this genetic engineering experiment. Findings from basic research on the gut-brain axis suggest that complex mental conditions, like depression, cannot be linked to the presence or absence of a single bacterial species, much less a single gene. Despite this cautionary warning, the students were driven forward by the disruptive ethos of the innovation economy, a bias to action that valorizes venturesome experiments (cf. Irani 2019:111).

Critical theorists have argued against a reductive approach to understanding happiness. Returning to etymological roots, Sara Ahmed notes that "having good 'hap' or fortune" was the original sense of the word "happy." While this now seems archaic, Ahmed (2010:22) insists that this old definition is important "as it refocuses our attention on the 'worldly' question of happenings." Engineering happiness, with a mood-enhancing drug or a genetically modified organism, thus seems doomed to produce an affective gap between expectations and the contingencies of the world (see Ahmed 2010:41).

Serotonin, the same neurotransmitter targeted by Prozac, was the focus of Rose's experiment. A growing body of evidence suggests that serotonin can be manipulated by microbes that normally live in our guts (see, i.e., Bencard and Whiteley 2018). The synthetic microbe created by Rose and her college friends produced this neurotransmitter at elevated levels. "We tested the production of serotonin," she said, "and got these pretty graphs showing an increase."

The pretty graphs led the London iGEM students to believe that they had designed microbial machines that would help people adapt to the world. They imagined new integrated feedback circuits that would enable the microbes to be responsive to the mental state of human hosts. But the students had no clear evidence that their "living machines" would actually establish stable symbiotic relations with people. Bacteria are constantly taking on new genetic material from viruses in the environment and sloughing off DNA sequences that are not useful (Flint et al. 2015:4). Rather than a stable machine with new genetic code hardwired into its system, they had a living organism that would adapt to new hosts, environments, and contingencies.

Even if the technical details of the experiment worked and the synthetic genes remained stable in the living microbe, the students also did not fully understand how it would interact with the human mind. Instead of predictably making people happy, antidepressants often produce other emotional and mental states. In the 1950s psychiatrists tested a number of experimental mood-enhancing drugs. Some potential antidepressants produced a manic euphoria, a sustained "high" (Healy 1999:52–53). Other compounds, like Prozac or Zoloft, resolved some symptoms of depression while causing side effects in some patients: nervousness, agitation, insomnia, sexual problems, and diarrhea.

The bacteria that Rose and her friends were working with, *E. coli*, are widely used as experimental organisms by students and other researchers around the world. These bacteria are normal parts of the human gut. "The strain we used is able to colonize the human gut and stay there for about three months," Rose said. But some strains of *E. coli* can produce nausea, bloody diarrhea, fever, and vomiting. Occasionally food-borne disease outbreaks are linked to this species. In absence of an experiment that actually gave these synthetic microbes to human volunteers, it is difficult to know with any certainty if this new strain would make people sick.

The biological laboratory where Rose worked at University College London has standard BSL-1 safety protocol designed for "work with low-risk microbes that pose little to no threat of infection in healthy adults." When I visited I donned a stylish orange lab coat and blue rubber gloves, plus plastic glasses, to protect against accidental splashes. Amid a collection of petri dishes, micropipettes, test tubes, and Bunsen burners there was a refrigerator with a living collection of happy hacked microbes sitting on the shelf.

Laboratory workers are at risk when they manipulate bacteria. If a gloved hand absentmindedly slips to the face, near the mouth, then someone might soon have to make a mad dash for the toilet, or become unexpectedly happy. Pranksters could decide to spike a drink with synthetic microbes. Or, on a dare, a student might suddenly decide to embark on some self-experimentation and swallow them down. Thus far, apparently, there have been no sudden outbreaks of happy mania, or mysterious cases of diarrhea, on the streets of London (fig. 4).

Haraway insists that we do not simply dismiss utopian technologists who aspire to enhance the human condition. "In the face of touching silliness about technofixes (or technoapocalypses)," she argues, "sometimes it is hard to remember

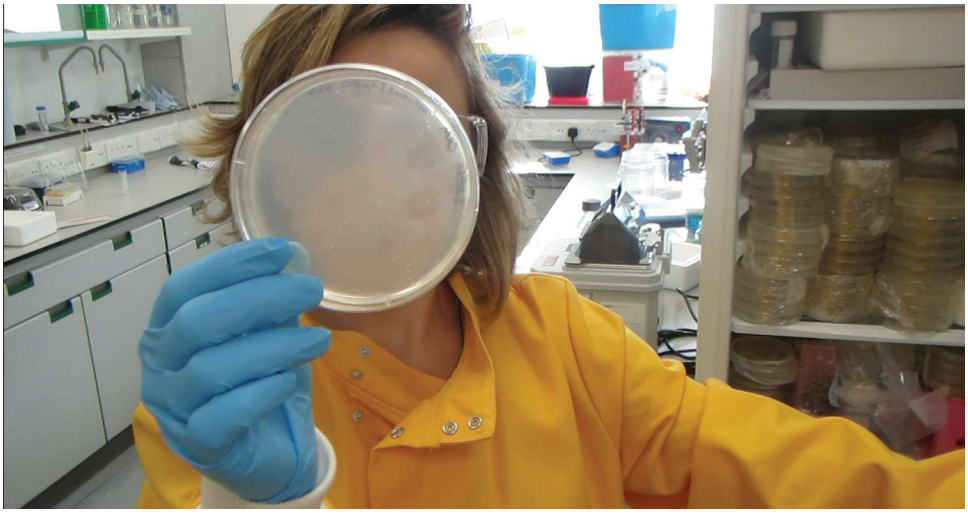

Figure 4. A petri dish with *E. coli*, designed to make people happier, at the University College London. Photograph by Eben Kirksey.

that it remains important to embrace situated technical projects and their people. They are not the enemy; they can do many important things" (Haraway 2016:3).

The iGEM students in London and Sydney were not the enemy, at least within the battlefields of the future as imagined by the FBI. With their ambitions to create new symbiotic microorganisms, they certainly were not trying to make anyone sick. But these students—and the faculty who supervised them—were perhaps limited in their imagination as they contemplated potential risks and benefits of the project. Their enthusiasm for novel technofixes was exposing the unsuspecting public to potentially serious risks to health and well-being.

Innovation and Inequality

Venturing beyond Europe, the United States, and other Anglophone countries like Australia, I found another iGEM team that was working on more immediate worldly problems with situated knowledge that they had gleaned from living in structurally marginalized situations. Osama Khan grew up in Pakistan where street food vendors offer reasonably priced and convenient meals. He knew that residents of urban areas who lack access to their own cooking facilities depend on street food. Since food carts often do not have clean water or refrigeration, their wares can be easily contaminated with dangerous microorganisms. Food-borne illnesses are common with street food and are difficult to avoid in absence of reliable knowledge.

Khan wears stylish glasses and a thick beard grown long around his chin. Along with his cosmopolitan group of friends—mostly freshmen hailing from Mexico City, Uzbekistan, South Korea, and Sudan—he was deeply aware of global inequity. More than a billion people worldwide have lived with food insecurity. They did not want to risk experiments with genetically modified bacteria in places where basic medical care was not available. The risks of working with live microbial agents are different when one studies at a university outpost in the Middle East or hails from a country where the United States has periodically engaged in strikes against bad guys in the Global War on Terrorism. Rather than create yet another experimental organism, the New York University (NYU) Abu Dhabi team decided to design a prototype test kit that could help people safely eat street food. They saw that government inspectors, food vendors, and consumers all needed effective and affordable tools to monitor existing pathogenic microbes.

The students at NYU Abu Dhabi initially focused on *E. coli*, the same microorganism at the center of University College London's Mind the Gut project. Like many other microbes, *E. coli* is a *quasi-species* with an underdetermined identity. Because of high rates of mutation and genetic recombination it is impossible to identify an "original" strain of this bacterium or have precise foreknowledge of its future forms (cf. Lowe 2010:625). Rather than create a new synthetic *E. coli* strain that would have unknown properties, the students at NYU Abu Dhabi focused their attention on strain O157:H7, which can produce severe bloody diarrhea and abdominal cramps—and even kidney failure in young children and the elderly. A company had just launched a new fast DNA test for this bug, on a paper strip that retailed for $119. The iGEM students from NYU Abu Dhabi wanted to improve on the design to see if they could make it affordable and accessible to the urban poor who depend on food from street vendors.

"Initially we wanted to make it for the ordinary consumer so you could go to a store, or a street food vendor and detect your food," Khan told me at the convention center in Boston. The team wanted to make something that was inexpensive, less than the price of a cheap meal, like a smart business card that people could carry around in their pocket.

As the students set to work—learning along the way as they incorporated insights from introductory university classes—they quickly ran into technical stumbling blocks. The idea of having a paper strip was abandoned. Instead they built

a prototype—a simple plastic box measuring 8 cm by 5 cm—to house a milky white agar gel. The device initially cost $65 to make, and it was designed to deliver results within 45 minutes. With more time, the students reckoned that they could build something more cheaply that would work faster. But they were unable to build a prototype that reliably worked in time for the iGEM competition. Like many of the iGEM teams I met in Boston, the NYU Abu Dhabi students were engaged in speculative storytelling.

These aspiring technologists had also interviewed people—regular customers at street food stalls as well as restaurant owners—to better understand how their device might work in the world. After just a few encounters they realized that the device was not a good fit for people who routinely eat at food stalls. They started circulating a survey through their social networks and gathered responses from people in over 30 countries who regularly ate food from street vendors and more established restaurants. Generally people were interested in the devices, but most were only willing to wait for 15 minutes to get results. As they learned more about the social worlds where these devices might be used, the students began to imagine how they might design something for use by street food vendors themselves—helping build trust among repeat customers in social environments where government food safety regulations were nonexistent, lax, or simply not enforced.

In March 2017 I visited the NYU Abu Dhabi campus—a bubble of academic excellence perched on the edge of the Persian Gulf, with an Olympic-sized swimming pool, a library boasting 16,000 books, and advanced research laboratories. Khan and his friends met me in the central plaza, where a grove of palm trees in straight rows shaded a social media hashtag rendered as a huge white sculpture: #myNYUAD. The students showed me a university-sponsored hacker space where they manufactured their prototype. Other student projects—an autonomous reefRover robot and an aerial drone designed for wildlife conservation—were scattered around the messy room. A white cat with orange and black calico patterns wandered into the space as the iGEM alumnae showed me the 3-D printer they used to create a prototype food sensor.

Over lunch I joined the students in speculation about how their device might be used in the future. We talked about expanding the range of microbes to include other bugs like *Salmonella* and *Listeria* that commonly cause food poisoning. Regular customers at food stalls had talked about concerns with chemical pollution—toxic exhaust from vehicles and contaminated ingredients. So perhaps the sensing device could be expanded beyond biological agents to also include chemical species (cf. Shapiro and Kirksey 2017). The NYU Abu Dhabi team was studying the precarious times of the present and was working to imagine subtle technological interventions that would allow for more livable futures (cf. Haraway 2016).

Ibrahim Chehade, a biology instructor at NYU Abu Dhabi, was one of the key staff mentors for Khan's team. As students began to explore other interests—as they moved on with their education and graduated—Chehade ensured continuity for the project across the years. Under Chehade's guidance, new students expanded the scope of the project—to detect additional microbes—while working to make a device that was more portable, faster, and affordable.

Students built a sleek black plastic pod, small enough to hold in the palm of your hand, for the 2018 iGEM competition. A sterile medical swab, attached to a fat pen-shaped plunger, was used to sample bacteria on the surface of food. A quick push on the plunger would flush the sample out into the most sophisticated part of the contraption: a microfluidics chip. That year NYU Abu Dhabi won an iGEM gold medal for the best diagnostic project. The university put out a press release: "Swab Before You Eat: An Affordable and Quick Way to Avoid Food Poisoning." A short announcement suggested that globe-trotters might like to take this "lab-on-a-chip" with them on their culinary adventures. "The joy of traveling, besides seeing the sights and sounds of a country, is enjoying local cuisines. For the more adventurous travelers, certain destinations also bring higher risk of food poisoning."[3]

The guiding vision of the project morphed somewhere between the original idea in 2016 and the press release of 2018. Instead of a device to help the urban poor live with food insecurity, a product was emerging that would help a different class of people protect themselves. In part, the team was just being realistic. If each test cost upward of $25, the price of a main dish in an upscale restaurant, it would not be affordable by people who sustain themselves with cheap eats at food stalls.

Chehade also told me that selling these devices to backpackers or business travelers is probably not realistic. Does anyone really want another clunky device—that would rattle around in luggage—interrupting the flow of every meal? Chehade came to see other people as likely end users of the device: government food-regulation authorities, as well as hotels, fast-food chains, supermarkets, and factories in the food industry.[4] As we talked about the values and ethical sensibilities of Osama Khan—his vision of helping people live with food insecurity—I engaged in some speculative storytelling of my own (cf. Ingold 2013:4).

I asked Chehade to imagine how the handheld plastic pod designed by his students might be put in the hands of new kinds of users. If the device were linked to a smart phone app—like Urban Spoon or Google Maps—perhaps people could use it to help evaluate and rate different food stalls. Smart phones have become ubiquitous in urban shantytowns around the world. Perhaps freelancers might like to buy the device and then go around testing street food vendors, while charging a small fee. Entrepreneurial users could become public health inspectors, food critics, and social media influencers all rolled into one. Stickers with a QR code could link individual street food vendors to results from recent tests, helping them build

3. NYU Abu Dhabi, 2019, Swab before you eat. https://nyuad.nyu.edu/en/news/latest-news/honors-and-awards/2019/january/swab-before-you-eat.html (accessed February 23, 2021).

4. NYU Abu Dhabi, 2018, Pathogene. http://2018.igem.org/Team:NYU_Abu_Dhabi/Entrepreneurship (accessed November 15, 2018).

trust among customers in places where sanitation inspections are not conducted by government agents.

Admittedly, my own speculation about possible uses of the emergent technology created by Chehade and his students had limits. Creating new gig economy jobs for freelancers risks reproducing precarious modes of life and fuels neoliberal fantasies about market solutions to problems that governments have failed to solve. It could be challenging to build a robust reputational economy around freelance food inspectors who might be tempted to accept bribes for a good rating, just like corrupt government officials. In an ideal world, states should ensure food security for the poor. But as governments increasingly abdicate responsibility, in an era of widespread deregulation, perhaps idealistic citizens and scientists have a role to play in repairing precarious worlds.

In 2019 Chehade and one of the students brought their sleek black microbe detector to a global accelerator that takes ideas from the NYU Abu Dhabi campus and helps students and staff "launch, develop, and scale their ventures."[5] The iGEM idea was selected as one of the top projects from Abu Dhabi. The entrepreneurial staff and students were given the opportunity to deliver a pitch to potential investors. Funds started flowing in, supporting a dedicated lab where new students started developing prototypes for next generation devices.

Students from NYU Abu Dhabi brought a new device to iGEM in late 2019: a prototype for a larger microfluidics diagnostic kit that would take saliva specimens from travelers to test them for communicable diseases. The aim was to prevent global outbreaks of infectious diseases by checking people as they transited through airports, border crossings, and health clinics. They identified diseases like Ebola, measles, and, remarkably, coronavirus as potential problems in the near future.

In the coming months, as one future scenario imagined by these students became a reality, commercial ventures all over the world began developing similar devices as fast and accurate coronavirus tests became an urgent priority. Rather than compete in this international marketplace, the next generation of iGEM participants from NYU Abu Dhabi expanded the scope of their project to address problems related to the health and well-being of other species.

The 2020 iGEM team from NYU Abu Dhabi uploaded a video to YouTube explaining the rationale for their latest project: "While we were scrambling to control COVID-19, amphibians have been suffering from their own pandemic for years now," explained the students. An emergent fungal disease, a kind of chytrid, has been killing salamanders and frogs en masse, pushing hundreds of species to the brink of extinction. A deadly chytrid "pandemic lineage" seems to have originated in the global marketplace as different fungal strains swapped genetic elements (Kirksey 2015:99). "Similar to COVID-19 the fungus spreads with travel, in the form of trade," the students said on YouTube. "However, testing at ports has been impossible since results come late and are expensive." Echoing the earlier concerns of the iGEM team from Missouri, the video reported that fungal diseases are also "wiping out millions of other animals, such as bats."

The NYU Abu Dhabi students could see that unregulated global flows of capital and biological materials were having disastrous ecological consequences. They began developing a rapid, point-of-care diagnostic device, with the goal of helping to identify deadly fungal infections in frogs and bats. The students exhibited plans for a fungal detector at the 2020 iGEM competition, which took place virtually amid ongoing pandemic travel restrictions. This time NYU Abu Dhabi did not win any awards or attract capital investments. Like many other iGEM projects that did not directly contribute to profit-making ventures, their visions remained in the realm of speculation.

Conclusion

The coronavirus pandemic has made the stakes of synthetic biology research crystal clear. Conspiracy theories about "gain of function research" at the Wuhan Institute of Virology have failed to find support among the scientific community (Calisher et al. 2020). Even still, there are many other documented cases of careless behavior by laboratory personnel that have resulted in the accidental release of deadly diseases (Piper 2019). As students experiment with genetic elements from known pathogens, they risk creating forms of life with unknown virulent properties. While the FBI agents take some steps to protect the public from the human health risks of synthetic biology, basic research is not being carefully screened for environmental risks. The US Federal Select Agent List, which guides synthetic biology risk management, has some notable omissions. Diseases that impact endangered species—like the white-nose disease of bats or the chytrid fungus that is driving the mass extinction of amphibian populations—are not included on this list of agents that require specific biosecurity protocol.

New forms of wild life are constantly emerging within biotechnology ventures. Sarah Franklin observes that "the new wild is the successor condition of the old wild, which meant nondomesticated, as in 'wild geese' or 'a wild boar.'" If "the wild" was once opposed to "the domesticated" in popular discourse, in the last few decades "what might be described as overdomestication or hypercultivation turns out now . . . to produce the other sense of 'wild,' as in something dangerous, risky, and out of control" (Franklin 2003:102). As legions of students join more established biotechnologists in applying engineering principles to life itself, it is reasonable to expect that some will succeed in producing new kinds of flesh-eating bacteria, infectious agents capable of generating contagious mania, or microbes that will produce future ecological disasters.

The power of the innovation economy is functioning predictably at the International Genetically Engineered Machine competition (see Rabinow and Bennett 2012). As FBI agents

5. startAD, 2021. https://startad.ae/ (accessed February 23, 2021).

promise to "safeguard science," their enforcement actions are protecting the profit-making fantasies of some while exposing others to unknown nightmares. Meanwhile entrepreneurs and investors are supporting iGEM projects that convincingly promise future economic wealth. Other projects focused on the interests of marginalized people or species have yet to find their champions among the thought leaders of Silicon Valley.

Since government agents have abdicated responsibility—focusing attention on stereotypical bad guys—the work of policing the imaginative horizons of synthetic biology has been delegated to the academic community. Scholars in the social sciences and humanities have long played a role in this governance work by serving on ethics committees and investigating critical issues. Benjamin Hurlbut suggests that it is a question not only about what sorts of basic biological research should be done but also about "what forms of expertise and moral imagination . . . what priorities, interests, and ethical commitments" should guide experiments (Hurlbut 2020:178). The passionate dreamers who attend the iGEM Giant Jamboree already bring diverse ethical commitments and moral imaginaries to the projects they exhibit in Boston every year. There is an opportunity to work with these students to develop more innovative and inclusive approaches to ethics and values. There is also an opportunity to resist the speed of the innovation economy and to demand more time for anticipatory governance.

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