



Caveat creator

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INTRODUCTION

Biohacking at home is becoming increasingly possible, even for the amateur. The biohacking space is at present minimally regulated, and the needed technical knowledge and equipment is increasingly accessible over the internet, conveniently mailed to you at home. DIY engineered microbes, gene therapy, and genetically modified tattoos and the like are on the horizon or are already happening.

In light of this, it is important to review where the existing technical, equipment access, and legal barriers for would-be biohackers exist today. This paper aims to provide a description of these challenges as they currently stand in the USA and to offer suggestions on how to address the current situation. Specifically, this paper will focus on savvy individual biohackers practicing genetic engineering at home and explore what such an individual might be able to accomplish.

Key terms and people

‘Biohacking’ and ‘Biohackers’ are subject to a variety of descriptions and definitions. In the context of this paper, biohackers will be those who focus on modifying biological systems, including bacteria, plants, animals, or humans explicitly through genetic modification. For the context of this paper, I will specifically refer to biohackers who are working at home.

‘CRISPR-Cas9’ is used as a system for engineering DNA, consisting of a Cas9 enzyme that can cut DNA and a RNA sequence that indicates where the Cas9 should cut. By changing the RNA sequence, the Cas9 enzyme can be quickly and easily retargeted, making it a convenient tool for genetic engineering.

‘DIY Bio’ is a movement that focuses on individuals doing their own biological experiments outside of institutional settings. DIY Bio includes a wide variety of different experiments and research focuses, ranging from synthetic biology to bioinformatics to biological art.

‘Genetic constructs or genetic circuits’ will refer to a piece or pieces of constructed DNA that encode for a given gene or set of genes that produces a desired effect when expressed. For example, a genetic construct encoding for green fluorescent protein should, if built correctly and put into a cell, produce green fluorescent protein and make the organism fluoresce green where the protein is expressed.

‘Green fluorescent protein’, or ‘GFP’, is a near ubiquitous protein used in genetic engineering assays, originally derived from jellyfish. Because GFP fluoresces a clearly visible green in the presence of blue light, it is a popular and easy to use gene for troubleshooting and testing genetic constructs.

‘Grinders’ are individuals who see themselves on the forefront of human modification. Many grinders implant subdermal devices including lights, magnets, and RFID chips that function as key cards to open doors or start keyless cars. Grinders will be defined as people who use hardware to perform body modification, almost entirely through self-experimentation. However, it should be understood that many grinders and biohackers consider the terms interchangeable.

‘Plasmids’ are small circular pieces of DNA that can be used to encode genes and express particular proteins. Plasmids can be inserted into a cell through a process called transformation or transfection. Many microbes routinely use and replicate plasmids alongside their more conventional genomic DNA.

‘Synthetic biology’ is here defined as the field of using genetic engineering to modify organisms and the construction of new tools to make genetic engineering easier and more powerful.

‘Josiah Zayner’ runs The ODIN (formerly the Open Discovery INstitute), a biological supply company focused on the DIY and educational biohacking market. Zayner is a public advocate of affordable, open source biohacking tools and has been at the center of several high-profile controversies including his kickstarter campaign for a \$150 home CRISPR kit and FDA backlash against his GFP-engineered beer.

Extent of biohacking practice

Understanding the extent of home biohacking can be challenging because many of these biohackers are working at home and not publishing their work. But it does appear to be happening, and it may become more popular if necessary equipment and knowledge become more accessible. At present, the website and DIY Bio community DIYBIO.org has over 2000 members worldwide, and some of these members operate independent labs from within their home.¹ Both Josiah Zayner of The ODIN and Brian Hanley, a PhD microbiologist, have been self-experimenting with DIY human gene therapy; Josiah Zayner of the ODIN has been publishing ongoing video updates of his experiments.^{2,3} David Ishee, a dog breeder, has been reporting on his experiments with sperm-mediated genetic engineering of mastiffs to address prevalent genetic disease.⁴ Sebastian Cocioba, a long island college dropout, has turned a spare bedroom into a lab for plant engineering and using CRISPR.⁵ While today these publicized garage

¹ <http://journal.frontiersin.org/article/10.3389/fpubh.2014.00115/full>

² <https://www.youtube.com/watch?v=imTXcEh79lw>

³ <https://www.technologyreview.com/s/603217/one-mans-quest-to-hack-his-own-genes/>

⁴ <https://www.youtube.com/watch?v=a-yIFjHJaoc>

⁵ <http://fusion.net/story/285454/diy-crispr-biohackers-garage-labs/>

biotechnologists and biohackers may be few in number, their success and public experiments may encourage others to enter the field. As the barriers to enter biohacking continue to decline, these early pioneers may establish trends that may signal the way forward for future biohackers.

KNOWLEDGE BARRIERS

Much has been made of the allegedly high knowledge barriers restricting successful implementation of biological technologies. Biosecurity experts reference the concept of 'tacit knowledge' to argue that successful synthetic biology and genetic engineering relies on implicit and unpublished technical knowledge.⁶ Since a self-taught biohacker would not have learned technique in an academic lab, they argue that the biohacker would be unlikely to succeed.

Community resources

In truth, however, many would-be biohackers are already experienced and trained in academic labs. Many biohackers transfer this formal academic and professional experience in molecular biology techniques into the home setting. Many of these experienced academic biologists also share their advice and technical skills with others online and through community biolabs such as Genspace in New York and BioCurious in the Silicon Valley.^{7,8} Furthermore, many college and high school students from more than 30 countries have participated in iGEM, an international competition for genetically engineered organisms founded in 2007.⁹

For those without an academic background in life science research and genetic engineering, these community biolabs also offer crash courses in key genetic engineering techniques. A 3-day, 4-hour a day Genspace NYC class for a \$300 fee (\$150 for students) teaches how to isolate DNA and perform a polymerase chain reaction (PCR), analyse DNA quality, use restriction enzymes, run gel electrophoresis, and run a transformation.¹⁰

Most recently, biohacking conferences have been developed that allow biohackers to come together and discuss projects and ideas they are developing in their own labs, whether in their garages or in community biohacker spaces. In 2016, Josiah Zayner formed the inaugural 'Biohack the Planet' conference, bringing together San Francisco bay area biotechnologists and biohackers to discuss pending projects and ideas.¹¹ In 2015, the infamous DEFCON conference on cybersecurity opened a 'biohacking village' to open a venue for talks on DIY biohacking and the Grinder movement.^{12,13,14} The DEFCON biohacking conference has also included lectures on reverse engineering key wet lab technologies such as -80°C freezers electronic pipettes,

⁶ <http://journal.frontiersin.org/article/10.3389/fpubh.2014.00115/full>

⁷ <http://biocurious.org/>

⁸ <https://www.genspace.org/>

⁹ http://igem.org/Main_Page

¹⁰ <https://www.eventbrite.com/e/biotech-crash-course-tickets-33545635900?aff=erelexpmlt>

¹¹ <http://biohacktheplanet.com/about-biohack-the-planet/>

¹² <https://www.defconbiohackingvillage.org>

¹³ https://www.youtube.com/watch?v=X9b_2jILLTg&t=2299s

¹⁴ <https://www.youtube.com/watch?v=y7egGKd1zkw>

and medical devices, making them easier for biohackers to operate, modify, and repair.¹⁵

Online resources

Many biohackers may want to work on ideas and projects that they have not previously explored in academic settings, or that might not be a focus of a local community biolab. For these researchers, many high quality online resources and forums exist for resolving possible questions and identifying possible starting points and protocols.

The iGEM BioBricks registry is an online repository of genes and ‘genetic parts’ associated with the iGEM.¹⁶ These genes follow a common format, making it easier to recombine these genes in new settings and to engineer organisms in novel ways. The registry currently includes over 20,000 parts, and although parts are inconsistently documented, the rating system and the ease of downloading sequence data from this registry makes the iGEM registry a valuable tool for biohackers when getting started with simple constructs.

OpenWetWare is a popular wiki-format website where laboratory scientists post protocols and information about research.¹⁷ OpenWetWare also includes links to online synthetic biology coursework, protocol guides, and advice on how to set up experiments. While intended primarily as a tool to share information between academic researchers, its open format and use by many life science labs make it another important resource for information on biohacking.

Community biolabs also post online instructions on how to build a number of interesting devices and experiments. For example, BioCurious, a community biolab in Sunnyvale, CA, has published documentation and instructions on how to build a Bio-Printer from scratch capable of printing *Escherichia coli* for a total price of \$150.¹⁸ While clever and precise placement of glowing *E. coli* is little more than a novelty, it demonstrates that lab equipment typically considered the domain of sophisticated academic labs is actually within reach of the individual biohacker.

It should also be pointed out that many ostensibly biohacking-related online forums are of dubious scientific help. Discussion of DIY genetic engineering on the biohack.me forums, while clearly active, is dominated by far-fetched topics including ‘augmenting the sense of smell’ by injecting nerve growth factor, ‘radiation resistant blood’, and augmenting the human body to incorporate a beehive.¹⁹ While these ideas probably exceed the limits of today’s science, these forums do indicate a population of people with a sincere interest in DIY genetic engineering.

Automation technology

A popular argument against the ease of biohacking is that many aspects of genetic engineering technique require expertise and an ‘indoctrination into the practices of biology’ that cannot be replicated by DIY enthusiasts.²⁰ While that is arguably false due

¹⁵ <https://www.slideshare.net/RyanMHarrison/def-con-24-reverse-engineering-biomedical-equipment-for-fun-and-open-science>

¹⁶ <https://biobricks.org/>

¹⁷ http://www.openwetware.org/wiki/Main_Page

¹⁸ <http://www.instructables.com/id/DIY-BioPrinter/>

¹⁹ http://forum.biohack.me/discussion/1757/hive-body-modification#Item_32

²⁰ <http://journal.frontiersin.org/article/10.3389/fpubh.2014.00115/full>

to the existence of online resources stated above, it may also be possible that modern automation technologies may render the need for manual pipetting increasingly obsolete. OpenTrons sells an automated pipetting robot for \$3000, ideal for the part-time biohacker who can set their OpenTrons to run while they are asleep or away from home.²¹ The alleged difficulty of pipetting may not deter a biohacker using lab automation equipment.

Safety

Knowing how to operate a lab safely is arguably the most critical skillset for any individual biohacker, since biohackers are often exposed to hazardous chemicals and biological agents in order to do their work. Most hackerspaces have proactive relationships with local FBI, police, and fire departments, and have established independent research boards and safety oversight, but such measures are inconsistently applied by individual biohackers.²² Josiah Zayner received criticism for tutorial videos that included storing bacteria in a kitchen freezer alongside food.

Biosafety

Thanks to the proliferation of community labs, the DIY Bio community has established an open FAQ site at DIYBio.org to curate responses to common biosafety questions and provide specific biosafety information.

DIYBio's recommendations for satisfactory Biosafety Level 1 (BSL-1) practice in the context of a home lab are not particularly arduous.²³ According to their listed guidelines, a biohacker should use a dedicated work area for work with microbes, i.e. not in a kitchen and ideally not in a bedroom. Biohackers should wash their hands before and after working, and should avoid eating, drinking, or storing food in the work area. Biohackers should decontaminate bacterial cultures before disposal by using freshly prepared 1:10 diluted Clorox bleach in contact with a culture for 30 minutes.²⁴ Biohackers should use a disposable or sanitized lab coat and fresh latex or nitrile gloves. Biohackers should work to avoid splashing bacteria or chemicals, and should wear eye protection when there is a risk of splashing. Lastly, biohackers should use suitable equipment for the task. These basic protocols are sufficient for working with nonpathogenic organisms, such as *E. coli*, yeast, and *Bacillus subtilis*; safe culturing of pathogenic organisms would substantially increase the associated cost and required expertise.²⁵ The CDC also provides an online manual for lab biosafety, called 'Biosafety in Microbiological and Biomedical Laboratories', commonly referred to as the BMBL, which may provide a useful reference to enable biohackers to move beyond BSL-1 practice.²⁶

²¹ <https://opentrons.com/robots>

²² https://www.nature.com/scitable/blog/bio2.0/diy_hardware_for_the_home

²³ <http://ask.diybio.org/questions/what-requirements-should-i-have-to-conduct-safe-and-harmless-experimen/>

²⁴ <http://ask.diybio.org/questions/other-than-autoclaving-how-do-i-safely-dispose-of-liquid-cultures-containing-e-coli/>

²⁵ <http://ask.diybio.org/questions/what-species-of-microorganisms-are-safe-to-use-at-home-and-what-is-the-preferred-method-of-destroying-them/>

²⁶ <https://www.cdc.gov/biosafety/publications/bmbl5/bmbl.pdf>

Chemical safety

Biohackers also regularly work with chemical agents that have similar, but distinct, methods for use. Similarly to biological material, biohackers should use lab coats and gloves when handling chemicals, making sure that the coat and gloves are the appropriate material for the chemicals being handled. Depending on the chemical hazards involved, a biohacker may want to consider a tyvek suit instead of a lab coat.²⁷ A chemical spill kit should be kept nearby and accessible for addressing spills, including absorbent material like kitty litter and neutralizing materials such as citric acid and sodium bicarbonate.²⁸

EQUIPMENT OR ACCESS BARRIERS

Before performing experiments, biohackers must first outfit their lab with the equipment and supplies they will need. We can divide these necessary supplies into hardware and wetware, both of which pose distinct challenges. Some more ambitious biohackers will also require the use of online cloud labs and access to test subjects, which will be discussed in further detail below.

Hardware

Having the correct hardware equipment is critical for building a DIY biohacker lab. Because biolab hardware is typically sold to academic and commercial biotechnology laboratories, new equipment can be prohibitively expensive and difficult to install and maintain. Creative biohackers have found solutions around many of these solutions. eBay can be a promising but unreliable source for affordable second-hand lab equipment. Amazon has also a broad selection of equipment although often at high prices. Carolina Biological Supply is also well known in biohacker communities as a great source for finding affordable equipment and wet lab supplies.²⁹ Purchased equipment can also be supplemented and customized at home with access to a consumer grade 3D printer.³⁰

Starter kits

The equipment required for outfitting a modern genetic engineering lab has become quite affordable and straightforward to purchase. For \$1149, The ODIN now sells a 'Genetic Engineering Home Lab Kit' including a PCR thermocycler, microcentrifuge, electrophoresis system, micropipettes, genotyping kit, and the necessary consumables for basic bacterial transformation.³¹ This kit also includes a 'DIY CRISPR Kit' including Cas9 and tracrRNA plasmids, which should make it easy to practice using CRISPR to reengineer bacteria.

²⁷ <http://ask.diybio.org/questions/what-would-you-consider-an-appropriate-chemical-spill-kit-for-a-diybio-lab/>

²⁸ <http://ask.diybio.org/questions/what-would-you-consider-an-appropriate-chemical-spill-kit-for-a-diybio-lab/>

²⁹ <http://www.carolina.com/>

³⁰ https://www.monoprice.com/pages/3d_printers?gclid=CjwKEAjw41jKBRDr6p752cCUm3kSJAC-eqRtj-01ymohDma5BnFD-3eOsnEsfoApJuK4bS1_P3rVthoCpAXw_wcB

³¹ <http://www.the-odin.com/genetic-engineering-home-lab-kit/>

More introductory alternatives include the Amino Bioproduction lab, a self-contained device for engineering and growing organisms.³² The Bioproduction lab includes tube heaters and coolers, a plate incubator, and a culturing chamber with independent ‘food’, ‘ingredient’, air, and waste ports. The Bento lab is a similar approach, coming with a built-in thermocycler, centrifuge, and electrophoresis box for €885.³³

Gel electrophoresis

Gel electrophoresis is a backbone of many basic synthetic biology protocols, and is often used to visualize DNA products and evaluate length of DNA fragments. Using online instructables, a biohacker could build a single self-contained device to cast gels, perform electrophoresis, and readout results for approximately \$200.³⁴ The patient biohacker may also find suitable equipment available on eBay.^{35,36,37}

Laminar flow hoods

If a biohacker is interested in working with pathogens or with sensitive tissue cultures, it will likely be necessary to use a laminar flow hood. This poses a problem, since laminar flow hoods built for institutional use can be large, expensive, complex to install, and difficult to build yourself.^{38,39} This poses a major hurdle to safe DIY biohacking, which may be partially resolved by relying upon outsourcing services.

Centrifuges

Centrifuges are a centerpiece of any biological lab, allowing the user to separate materials of differing densities by rapidly spinning samples. Tabletop centrifuges are relatively affordable, with a barebone mini centrifuge costing \$121 from SoCal Biomed.⁴⁰ One DIY design published in Popular Science includes a 3D printed scaffold for holding tubes, attached to a dremel tool.⁴¹

Fridges and freezers

Most conventional biological labs have three distinct fridges and freezers, set to 4°C, -20°C, and -80°C, and are used to store samples and reagents. The first two are mostly interchangeable with typical consumer-grade kitchen freezers, with the caveat that ‘frost-free’ freezers will often fluctuate the temperature above -20C to reduce ice-crystal formation. On the other hand, -80°C freezers are expensive and difficult to

³² <https://amino.bio/collections/started-kits/products/bioproduction-lab>

³³ <https://labiotech.eu/bento-lab-kickstarter-dna-biohacking-synbio-startup/>

³⁴ <https://www.ponoko.com/laser-cutting>

³⁵ <http://www.ebay.com/itm/Bio-Rad-Wide-Mini-Sub-GT-Agarose-Gel-Electrophoresis-System-with-Gel-Caster-/371974334085?hash=item569b65e685;g:isIAAOSw8HBZNYHP>

³⁶ <http://www.ebay.com/itm/EC105-EC-105-E-C-105-Digital-power-supply-cell-gel-electrophoresis-bnr-/182505669837?hash=item2a7e2f84cd;g:kaYAAOSwFnFWDAGN>

³⁷ http://www.ebay.com/itm/Thermo-Owl-Easycast-B1A-10-Compatible-Gel-Comb-10-Teeth/272693601732?_trksid=p2045573.c100507.m3226&_trkparms=aid%3D555014%26algo%3DPL.DEFAULT%26ao%3D1%26asc%3D41375%26meid%3Dd0078e4a806d49ed9ebc1bee01407086%26pid%3D100507%26rk%3D1%26rkt%3D1%26

³⁸ <http://ask.diybio.org/questions/is-it-a-good-idea-to-build-my-own-laminar-flow-hood/>

³⁹ <http://www.ebay.com/itm/THERMO-FORMA-CLASS-II-A1-BIOLOGICAL-SAFETY-CABINET-BIOSAFETY-BSC-LAB-HOOD-1200-/332238017397?hash=item4d5aedd375;g:AIAAOSwX9FZKKBA>

⁴⁰ <https://www.socalbiomed.com/waverly-c100-mini-centrifuges.html>

⁴¹ <http://www.popsci.com/diy/article/2013-07/how-build-your-own-diy-centrifuge>

install by a typical biohacker. A new -80°C freezer can cost around $\sim\$10,000$.⁴² Instead, biohackers can use more conventional -20°C freezers for storing samples that will hold for around one year.

PCR thermocyclers

The nascent open source biotech hardware movement has also opened up opportunities to make your own affordable equipment, such as the OpenPCR machine. The OpenPCR machine has been available for the last five years, and provides a fully functional, open source PCR thermocycler suitable for PCR, a standard procedure which allows scientists to amplify a small concentration of DNA into many more strands of DNA.⁴³

DNA sequencers

Sequencing can now be conducted in-house using a flash-drive sized minION sequencer, costing \$1000 for the sequencer itself and depending on bulk purchasing, \$500 to \$900 for the expendable flow cell cartridge.⁴⁴ The minION sequencer conveniently connects directly to a USB drive on the computer of your choice, where a downloadable algorithm can then analyse sequencer data to compose the genome sequence. Conventional illumina sequencers are designed for high throughput and beyond any reasonable biohacker budget, but online suppliers on Science Exchange can provide outsourced services for biohackers interested in sequencing.

Autoclaves

A designated pressure cooker can provide an adequate substitute to an autoclave for sterilizing dishware and other material.⁴⁵

Incubators and shakers

There are a number of online tutorials for how to build a shaker incubator using easily accessible parts.⁴⁶ Buying a new shaker incubator intended for academic use can be prohibitively expensive, approximately in the \$2000 range.⁴⁷ Most microbial cultures will still grow without an incubator, at a slower rate that may be preferable for the hobbyist biohacker. Armpits can double as 37° incubators, albeit impractical for most use cases.

Electroporators

While beyond the realm of conventional biohacker equipment in terms of price and sophistication, the recent interest in human genetic engineering facilitated by electroporators warrants a discussion on how an electroporator could be found by a biohacker. Electroporators are used to introduce an injected plasmid into surrounding cells by applying a current which appears to increase transport of these short DNA plasmids. Electroporators are much more of a niche item than other equipment found on this list, and

⁴² <https://www.laboratory-equipment.com/laboratory-equipment/revco-ultra-low-temp-freezers.php>

⁴³ https://www.nature.com/scitable/blog/bio2.0/diy_hardware_for_the_home

⁴⁴ https://store.nanoporetech.com/minion/sets/?___SID=U

⁴⁵ <http://www.instructables.com/id/How-to-Sterilize-Autoclavable-Materials-at-Home-us/>

⁴⁶ <http://makezine.com/2010/12/06/diy-laboratory-shaker/>

⁴⁷ http://www.southwestscience.com/IncuShaker_Mini.html

can be difficult to find for a DIY enthusiast. For biohackers willing to invest in a new electroporator, BTX sells *in vivo* electroporation equipment online.⁴⁸ A DIY electroporator could theoretically be built using a square wave generator, a boost converter, and a needle array. Josiah Zayner has been developing a number of alternative approaches for human genetic engineering with the intention of reducing cost, published through a series of video updates.⁴⁹

Gene guns

A gene gun is a device typically used for engineering plants, by ejecting DNA-coated gold particles at high speed into the plant. A DIY gene gun can be built for ~\$230 following online instructions provided by the BioCoder Journal.⁵⁰ However, most gene guns require the use of spermidine, which can be difficult to find.

Reagents and chemicals

By far the most difficult aspect of building out an ordinary home biolab is acquiring reagents and chemicals. There are a number of reasons for this challenge. First, reagents are expended or go bad over time, meaning that stocks must be occasionally resupplied. Second, it can be challenging to find a consistent source for these reagents, so when re-supply comes due it may be necessary to change to an alternative chemical or approach which may change scientific results. Third, these chemicals can be difficult to store safely in a home lab, given that many are flammable, toxic, or carcinogenic. Fourth, many chemical and biological reagent suppliers are hesitant to sell to individual biohackers at residential addresses, more so than hardware vendors like Amazon or eBay.

One source for viable wet lab materials, albeit quite inconsistent in supply and of uncertain quality, is eBay. For example, GeneExpresso *In Vivo* transfection supplies are available for \$30 in this listing.⁵¹ At time of writing, there were 15,361 results on eBay under their lab chemicals section, including cellulose, EDTA, and many other common chemical reagents.⁵² Amazon has also a broad category of Industrial & Scientific materials which offers another venue for purchasing key hardware and wetware supplies.⁵³

While many chemical suppliers have long-held online stores, most established reagent providers have restricted selling supplies to individuals at residential addresses. However, recently founded companies including Josiah Zayner's The ODIN have stepped in to sell explicitly to the DIY Bio community, providing tubes, plasmids, basic supplies, equipment, and bacterial strains to biohackers.⁵⁴ Companies including NEB and IDT are more flexible about sending materials to residential addresses, whereas Sigma Aldrich and chemical suppliers are more restrictive.⁵⁵

⁴⁸ <http://www.btxonline.com/products/electroporation-systems.html>

⁴⁹ https://www.youtube.com/watch?v=velrYp_Nez0

⁵⁰ <https://www.oreilly.com/ideas/how-to-build-and-use-a-gene-gun>

⁵¹ <http://www.ebay.com/itm/GeneExpressoMax-Transfection-Reagent-More-Transfected-Cells-than-Lipofectamine-/111413711459?hash=item19f0c65263:g:SPAAOSwibJTyHFd>

⁵² https://www.ebay.com/b/Lab-Chemicals/104233/bn_16563419

⁵³ https://www.amazon.com/s/ref=nb_sb_noss?url=search-alias%3Dindustrial&field-keywords=

⁵⁴ <http://www.the-odin.com>

⁵⁵ <https://www.youtube.com/watch?v=tH9f9502zyo>

Online outsourcing

Cloud labs offer online access to a semi-automated biolab workspace where scientists can input protocols and materials and receive results and data from the lab.⁵⁶ In addition to providing an alternative workspace, these cloud labs may offer access to specialized equipment and sterile environments that would be prohibitively expensive or difficult to operate at home. At present, these cloud labs are focused on selling to academic labs, but may open up more to individual biohackers as the service continues to grow.

An alternative and more practical option for biohackers is the growing online market Science Exchange, which performs scientific experiments and prepares materials on a contract basis.⁵⁷ Science Exchange partners with over 2500 labs offering a broad range of services. At time of writing, 27 providers offer virus production, 29 providers offer gene synthesis, and 11 providers offer CRISPR-Cas9 vector generation.

Test subjects

Because home biohackers operate outside of typical academic and institutional settings, it can be difficult if not impossible to acquire legitimate mammalian or human test subjects for more sophisticated work. It therefore comes as little surprise that many DIY biohackers including Josiah Zayner have focused on self-experimentation as a means to test their ideas. While the prospect of self-experimentation at home may be alarming, there is a long history of self-experimentation even within traditional academic and professional institutions, such as Barry Marshall's well-documented self-experimentation with *Helicobacter pylori* in 2005 and subsequent Nobel Prize.⁵⁸ Other biohackers, such as David Ishee, have worked on genetic engineering of dogs.⁵⁹

CIRCUMVENTING INSTITUTIONAL ACCESS BARRIERS

As many biohackers have found, many reagent providers and scientific supply companies will refuse to send equipment and chemicals to a home address. Many biohackers get creative using the suppliers listed above, scouring eBay to find reagents they need. For biohackers willing to be slightly deceptive, however, many biohackers have found success circumventing restrictions on sales to individual biohackers.

Josiah Zayner, the founder of the ODIN, has listed a set of 'best practices' for circumventing barriers against selling to individuals. Zayner recommends the following advice.⁶⁰ (1) Refer to yourself as a business, purchase the domain name for that business and send emails from that domain name, to look more official. (2) Add a PhD to your name in your emails, since no one will check. (3) Set up a FedEx account number to get around explicitly shipping to a home address. Zayner also says that one of the largest plasmid vendors encouraged Zayner to take these steps to bypass their own review system. Zayner used this purchased plasmid to express GFP in his arm using a variety of experimental injection techniques. Existing self-regulation on the part of the

⁵⁶ <https://emeraldcloudlab.com>

⁵⁷ <https://www.scienceexchange.com/dashboard>

⁵⁸ <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3298919/>

⁵⁹ <http://fusion.net/story/285454/diy-crispr-biohackers-garage-labs/>

⁶⁰ <http://www.ifyoudontknownowyknow.com/2017/01/genetic-designer-part-ii-dna-got-what-i.html>

major supplier companies is an inconvenience and a deterrent for would-be biohackers, but does not meaningfully curtail access to reagents biohackers want.

LEGAL BARRIERS

Existing legal barriers in the USA to biohacking are unclear and mostly unenforced. Most regulatory agencies have for now taken a mostly hands-off, wait-and-see type approach. Unlike other countries such as Germany, there are no specific licensing requirements for performing genetic engineering in most of the USA.⁶¹ Furthermore, there is no federal law prohibiting human germline engineering outside of clinical and research settings in the USA, although the FDA has ability to regulate research and clinical trials of gene and cell therapies.⁶² Most academic and institutional labs operate in compliance with self-regulating moratoriums that restrict the most controversial projects, but individual biohackers might be motivated in the opposite direction.

Several special cases exist where the illegality of home biohacking is clear. The use of agrobacterium to engineer plants is regulated by the USDA.⁶³ Another notable legal issue may come up when individual biohackers attempt to culture soil bacteria, as soil commonly contains small concentrations of known human pathogens including *B. anthracis*, also known as anthrax. Possession, use, storage, and/or transfer of anthrax without registration and certification with CDC Select Agent Program is a federal crime.⁶⁴

Medicine

One interesting solution that may permit legal biohacking medical products is to consider them under magistral drug production. Typically considered as drug compounding, magistral drug production involves a licensed pharmacist producing a one-off dose of medication to satisfy a specific patient prescription. Interestingly, magistral production falls outside FDA marketing authorization and GMP manufacturing rules because no drugs are intended for a specific patient and do not cross state lines.⁶⁵ Thanks to a US patent exemption on personal use, these magistral drugs may also be exempted from intellectual property protection.

Zoning

Zoning laws surrounding biohacking are fuzzy and inconsistent, given that zoning laws are almost certainly never written with home biohackers in mind. Many zoning codes do not explicitly list life science research laboratory use.⁶⁶ In some cases, a biohacker may be storing flammable chemicals or other hazardous materials which may fall under building code requirements. Properly storing these reagents and keeping limited quantities should ameliorate this issue. Biohackers regularly use carcinogens and other hazardous reagents that have in the past been argued as requiring review under

⁶¹ http://www.slate.com/articles/technology/future_tense/2017/05/the_fuzzy_regulations_surrounding_diy_synthetic_biology.html

⁶² <https://www.nature.com/nbt/journal/v35/n6/full/nbt.3884.html>

⁶³ <https://www.oreilly.com/ideas/how-to-build-and-use-a-gene-gun>

⁶⁴ <http://ask.diybio.org/questions/how-do-i-make-my-lab-bsl-1-compliant/>

⁶⁵ <https://www.fda.gov/downloads/Drugs/GuidanceComplianceRegulatoryInformation/PharmacyCompounding/UCM446238.pdf>

⁶⁶ https://www.wilmerhale.com/uploadedFiles/Shared_Content/Editorial/Publications/Documents/microbes-mice-minefields-unique-issues-developing-leasing-life-science-facilities.pdf

environmental impact statutes. Some municipalities, notably Cambridge Massachusetts, have local licensing requirements for working with recombinant DNA which would restrict most individual biohackers.⁶⁷ These local licensing requirements are increasingly rare, having been phased out over the past several years.

Enforceability?

Even if a biohacker's work violates a local law, are these laws practicably enforceable? A garage used by a biohacker is, from the outside, not noticeably different than any other garage. Most equipment used by a biohacker is small enough that it can be moved easily in and out of a home inconspicuously. There are few devices that make loud noises, and although *E. coli* or yeast produce a distinct smell, the smell of yeast is more probably explained as from baking bread or homebrewing than by genetic engineering. Very active life science research may produce large amounts of waste in the form of pipette tips, gloves, and spent tubes, but most biohackers would not produce significantly more trash than an ordinary resident. Most of this waste can be thrown in normal trash, except for a few rare mutagenic compounds that should be disposed of in hazardous waste. This calls into question the practicability of enforcing regulations on DIY biohacking.

HOW TO RESPOND

We should support biohacking for two reasons. First, because bringing diverse perspectives and fresh eyes to long-standing biological problems may reveal critical new insights. The Information Technology businesses of today owe much to a hacker ethos and early garage hackers like Hewlett Packard, Atari, and Apple. Unlike their institutional peers, biohackers face fewer disincentives toward sharing negative results and collaborate with others by necessity. Biohackers bring with them many of the successful habits and methods of thought from Information Technology and bring them to biology, refreshing the field. Biohackers are refocusing the field toward building better tools and driving down cost. By permitting individual biohackers to operate in public, we make it easier to anticipate and prepare for new technical capacities as they develop. Through public forums, biohackers can share the safest and most effective protocols, keeping us all safer in the process.

Technical solutions

Biohackers have demonstrated a sincere interest in breaking synthetic biology and genetic engineering techniques out of the lab and moving into local community labs and even home biolabs. And yet, the cost barriers and difficulty of acquiring equipment are insufficiently high to prevent biohacking and insufficiently low to encourage safe use of the appropriate tools and laboratory setting.

The recent interest in biological cloud labs could provide a compelling solution to the risks biohackers pose without restricting biohackers ability to carry out experiments as they see fit. If a cloud lab service addressed the biohacker community, it could help reduce costs, reduce technical hurdles, and improve safety among those interested in conducting their own experiments.

⁶⁷ https://www.wilmerhale.com/uploadedFiles/Shared_Content/Editorial/Publications/Documents/microbes-mice-minefields-unique-issues-developing-leasing-life-science-facilities.pdf

Legal solutions

Legal solutions are difficult to find because of the challenge associated with identifying home biohackers and evaluating the hazards posed by their work. Biohackers can work safely, and can do so with homegrown or unconventional equipment. Most biohackers are less hazardous to their surroundings than an ordinary high school biology lab, in that they work in smaller quantities of material and with greater control over who enters and exits. That said, what follows would appear to be a reasonable set of guidelines for biohacking as it develops:

- i. Biohackers should be held legally accountable for any damage produced by an unintended environmental release of an organism, pathogen, or chemical. This accountability should extend to improper disposal of waste.
- ii. A biohacker should take reasonable steps to ensure that protocols are performed in the manner safest to the environment, themselves, and others.
- iii. Biohackers should be open and transparent about their work, so that other biohackers can learn from their experiences and so that the development of any potentially hazardous technologies can be monitored.

If regulators are adamant about restricting the DIY Bio movement, the current bottleneck is in access to wet lab reagents. If suppliers were restricted from selling to non-institutional purchasers, at-home biohacking would be greatly curtailed, simply because it would be much more difficult to access the necessary materials.