SYNTHETIC BIOLOGY PROJECT / SYNBIO 5

SEVEN MYTHS & REALITIES

about Do-It-Yourself Biology

SYNBIO 5

Synthetic Biology Project

Wilson Center

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SEVEN MYTHS & REALITIES about Do-It-Yourself Biology

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SYNBIO 5/November 2013

Introduction

Do-It-Yourself Biology, or DIYbio, is a global movement spreading the use of biotechnology beyond traditional academic and industrial institutions and into the lay public. Practitioners include a broad mix of amateurs, enthusiasts, students, and trained scientists, some of whom focus their efforts on using the technology to create art, to explore genetics, or simply to tinker. Others believe DIYbio can inspire a generation of bioengineers to discover new medicines, customize crops to feed the world's exploding population, harness microbes to sequester carbon, solve the energy crisis, or even grow our next building materials.

Many Do-It-Yourself participants—or DIYers—believe that wider access to the tools of biotechnology, particularly those related to the reading and writing of DNA, has the potential to spur global innovation and promote biology education and literacy.

On the other hand, many policymakers and journalists fear that greater access may give rise to new security risks. They fear that bioterrorists could exploit the newly available technology to design, build and spread disease. A 2008 congressional commission, for example, predicted that the United States would suffer a bioterrorist attack by 2013.[1] More recently, *The Atlantic* magazine predicted that in as little as three years anonymous biohackers might engineer a virus that targets the U.S. president.[2]

At the crux of these fears is a miscomprehension about the community's ability to wield DNA and manipulate life.

The reality, as it stands, is that DIYbio is far more innocuous than either vision. These viewpoints are grounded in speculation about what could happen rather than data about what is happening in the DIYbio movement. This is chiefly because almost no work has been done to survey the DIYbio community, its membership, organization, capabilities, and goals. Most information cited in reports and in the media is anecdotal or speculative, citing what lay people may do based on the dramatically falling costs of equipment and reagents. The Synthetic Biology Project at the Woodrow Wilson International Center for Scholars has surveyed the community for the first time, finding both expected and unexpected results (For full results see Appendix 1).

This report assembles seven of the media and policy community's most pervasive myths and expectations about the DIYbio movement, then outlines the realities based on the data generated from the community-wide survey. Finally, it presents six policy recommendations.

A Short History of the DIYbio Movement

The concept for a popular movement of amateur biotechnologists—what eventually became DIYbio—began to take shape around 2000, after a working draft of the human genome was completed by the Human Genome Project. Articles in the media predicted that amateur genomicists would soon explore DNA, in the same way amateur astronomers had been exploring the cosmos.[3,4]

Five years later, Rob Carlson, a senior researcher at Washington University, demonstrated the ease of building a home lab in the pages of *Wired* magazine.[5] He built a lab in his garage from equipment bought online to develop a protein-tagging system he'd hoped to spin into a company. Carlson, like the first DIYers, was far from amateur. He had worked closely with the first synthetic biologists, a burgeoning group of scientists who sought to simplify molecular biology by treating it as an engineering discipline.

While Carlson published his article in print, in Cambridge, Massachusetts Jason Bobe and Mackenzie Cowell launched the DIYbio.org message board online. The site was used to announce events at local bars where small groups gathered to perform simple biology experiments, such as extracting DNA from strawberries.

Like Carlson, they too were deeply connected to the burgeoning field of synthetic biology. Bobe worked for Harvard bioengineer George Church, one of the founders of the discipline, while Cowell worked as an employee of the International Genetically Engineered Machines (iGEM) competition, a synthetic biology contest for high school and college undergraduates.[6] As synthetic biologists made bioengineering technology easier and more accessible, Bobe and Cowell promoted wider adoption among the public.

Following the 2008 recession, Bobe and Cowell's efforts in biology tapped a wider pool of disenfranchised graduates and highly skilled professionals who had seen the DIY ethic in other fields—craft culture in urban areas, Silicon Valley startups, and electronics hackerspaces.* Simultaneously, shrinking biotech companies began selling used equipment on Ebay at prices affordable to lay people, while the cost of reading and writing of DNA sequences became inexpensive enough for hobbyists.

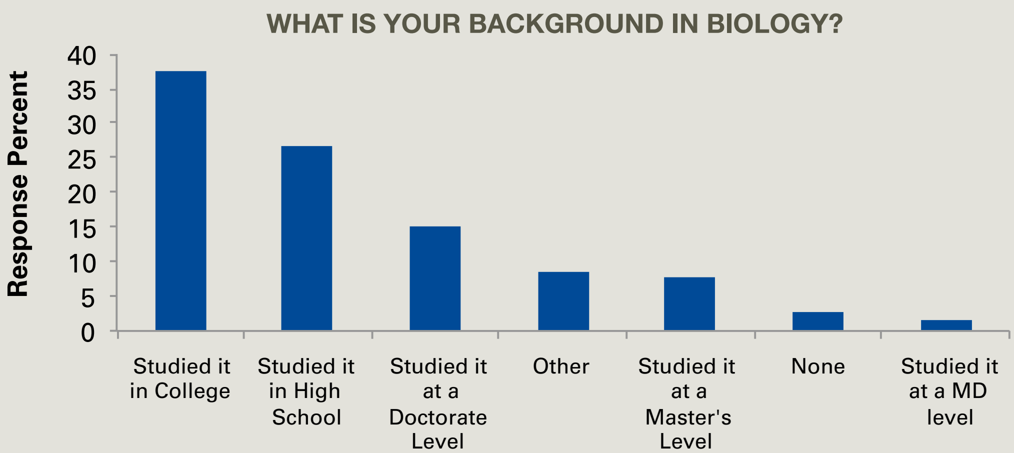
Within two years, DIYbio had evolved. People who were originally doing kitchen or garage experiments began organizing and setting up dedicated labs in commercial spaces. They pooled resources to buy, or take donations of, equipment, and began what have become known as "community labs." These labs sustain themselves on volunteers, membership donations, and paid classes. The first opened in Brooklyn, NY, followed by another in Sunnyvale, CA. Courses include lessons in synthetic biology, neuroscience, bioart, genetics, and basic biotechnology.

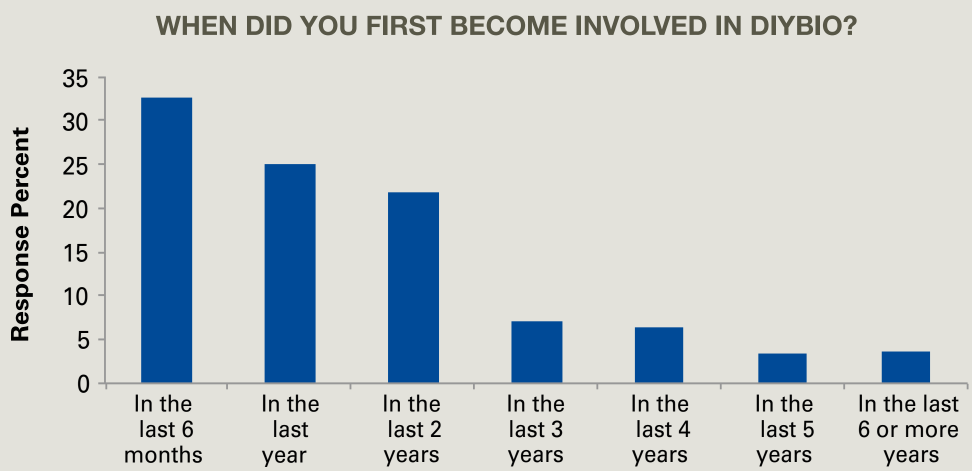
* A hackerspace (also called a makerspace) is a community workspace where people gather, socialize, and collaborate on computers, technology, and science projects.

Survey of Community

A total of 359 respondents replied to the online survey, which was conducted from January to March 2013. For details on how the survey was conducted, see Methods, page 24. On average, the DIY community is more educated than the general population: 19 percent have obtained a doctorate level degree (i.e. MD, PhD, JD), 27 percent have obtained a master's degree, and 37 percent have completed college. They are also younger than the general population: 15 percent are under 25 years old, 21 percent are between 25 and 35 years old, 42 percent are between 35 and 45 years old, and 23 percent are 45 years and older. The vast majority of the DIYers that responded to the survey are from North America, with 82 percent from the United States and 4 percent from Canada. Some 10 percent are from Europe, 1 percent is from Asia, and 2 percent are from other geographic areas (i.e., South America, Australia).

Of the 305 resondents, 46 percent work at a community lab, 35 percent work at hackerspaces, 28 percent work at an academic, corporate, or government lab (ACG), 26 percent work at home, and 8 percent of respondents work at home exclusively (see page 7).





Many DIYers Work in Multiple Spaces

To further examine the question of where DIYers conduct their experiments, respondents (267 total) were given the opportunity to provide multiple locations. Of those that only reported one location (150 respondents), one works in an academic, corporate, or government lab (ACG), 37 work in a hackerspace, 58 work in a community lab, and 23 work at home.

Respondents replying that they work in two locations (93 respondents), we find that five work in an ACG lab and a hackerspace, 13 work in an ACG lab and at home, 18 work in an ACG lab and a community lab, 15 work in a hackerspace and at home, 32 work in a community lab and a hackerspace, and 10 work in a community lab and at home.

For those working in three places (19 respondents), five work in an ACG lab, a community lab, and at home; two work in an ACG lab, a hackerspace, and at home; six work in an ACG lab, a hackerspace, and a community lab; and six work in a hackerspace, a community lab, and at home.

Of those working in four places (5 respondents), all reported to work in an ACG lab, a hackerspace, a community lab, and at home.

What is Known About the Movement

DIYbio continues to grow rapidly. There are currently at least 14 community labs across Europe and North America and 18 regional DIYbio meeting groups. The DIYbio message board now boasts 3,300 members. The movement has grown more in the last six months than any other time. Some 33 percent of active participants joined the community in the latter half of 2012, according to our survey.

There is no single voice that can speak on behalf of the community. As with any broad and decentralized movement, there is no way to know what every member is doing at any given time. This makes it difficult to assess safety and security risks and to rule them out with certainty. The results of this survey are not intended as a definitive account of this community, but they should, however, shine some light on activities within the DIYbio community.

The survey illustrates that, thanks to connections between individuals and groups, information is shared widely throughout the community. DIYbio is deeply influenced by open-source culture and stresses transparency in its code of conduct. Rather than hide their work, members are more likely to emblazon their accomplishments on the Internet.

Furthermore, because most DIYers do their work within shared labs, they do not work anonymously. If an individual is working unsafely, or nefariously, the community of lab members working alongside him or her will likely be the first to notice and respond.

Community labs in particular partner with government and academic institutions. For example, most community lab directors in the United States have established relationships with their Federal Bureau of Investigation counterparts (see Myth 7).

From our survey results, only 8 percent of DIYers work in their homes exclusively. Of these, many avidly discuss their work online. And almost all of them are working on projects that can be carried out with minimal biosafety precautions, designated by Centers for Disease Control and Prevention as Biosafety Level 1 (BSL 1), where organisms are nonpathogenic and can be worked with on open lab benches.[7]

The DIYbio community presents a number of educational and entrepreneurial opportunities for the public. DIYers offer peer-to-peer training on cutting-edge biotechnology for a price well below traditional institutions. They reach out to the lay public and students with hands-on training and education that would otherwise be available only to university students and those in industry. The ideas and products emerging from DIYers already present a variety of academic and industrial applications, including inexpensive biotech equipment and diagnostic tests for the developing world.

Myth 1: DIYers work anonymously and solitarily

Reality: Several factors combine to create the perception that DIYers work anonymously and alone. First has been a failure in labeling. The name "do-it-yourself" suggests working alone. The phrase was borrowed from a larger, burgeoning crafts movement, but as early as 2009, the coiners claimed "do-it-together" would have been a more appropriate title.[8]

To add to the misperception, between 2005 and 2011, the media focused on a handful of individuals who had built labs in their closets and garages. These came to symbolize DIYbio. Headlines followed like "Biotech in the Basement" *(Nature Biotechnology),*[9] "The geneticist in the garage" *(The Guardian)*[10] and "In Attics and Closets, 'Biohackers' Discover their inner Frankenstein" *(The Wall Street Journal)*.[11] These portraits may have been accurate in 2009, but group labs formed immediately after the initial wave of coverage.

In the past, policymakers feared that a wide, decentralized group of DIYers would be difficult to find and reach. Over the last three years, DIYers have largely organized on their own. They now largely gather in regional hubs that adhere to lab safety protocols. But while the landscape of risk has changed, the perception of it has not.

Nearly a decade since the movement began, 92 percent of DIYers work in group spaces. These split between community labs, group labs solely devoted to biotechnology, and electronics hackerspaces that house DIYbio labs. They also include traditional corporate, academic, and government labs.

The myth that DIYers work solitarily does not bear out with the survey. Only 8 percent, or 23 respondents, work exclusively in home labs. This data suggests that DIYers are also well networked. That is, someone who works at home is also likely involved with a group. As such, governmental agencies wishing to communicate with DIYers can reach most DIYers by liaising with already organized groups. The 8 percent who work exclusively in home labs, however, may be harder to reach.

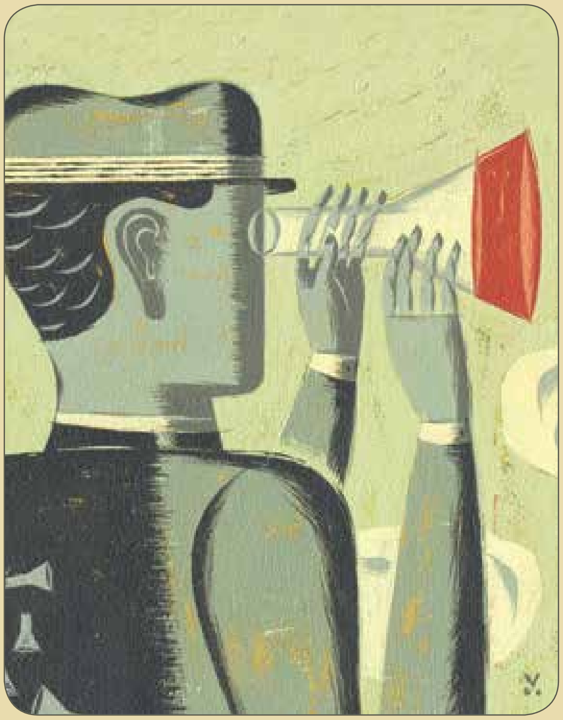
Myth 2: DIYers are capable of unleashing a deadly epidemic

Reality: A number of news articles have predicted that DIYers might produce deadly viruses or epidemics. In 2009, *The Wall Street Journal* asked, "Are biohackers a threat to national security?"[12] Three years later, during the debate over the release of a controversial study on mutant bird flu, *The New York Times* declared amateur biotechnologists might exploit the data to turn the deadly virus into an epidemic.[13] *The Atlantic* imagined that in 2016—just three years from now—anonymous biohackers could design a virus to pass innocuously through the human population until it reaches the president, targets his RNA, and kills him.[14]

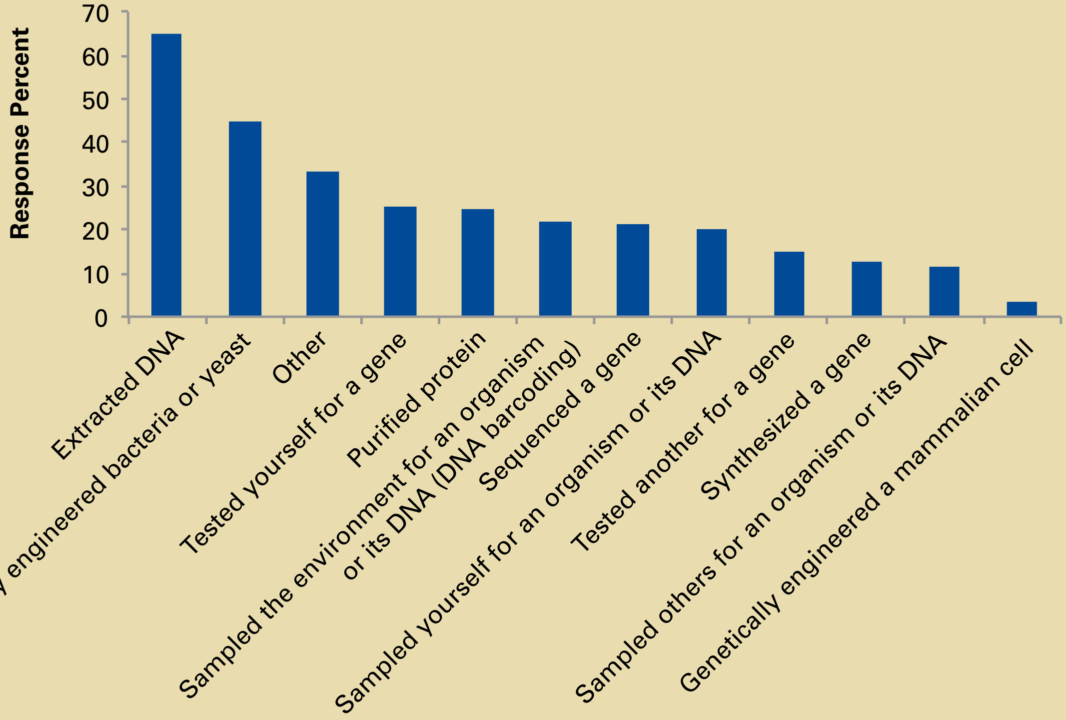
At present, these fears are unfounded. The community survey suggests that, far from developing novel pathogens, which would require the skillset of a seasoned virologist and access to pathogens, most DIYers are still learning basic biotechnology. In the last two years, only 13 percent of DIYers surveyed have synthesized a gene, a first step in basic bioengineering, while some 45 percent have added a gene to bacteria. If we were to use computers as an analogy, this would mean that few have ever written a program, and less than half have ever installed a premade program.

According to the survey, DIYers work with BSL 1 organisms with few exceptions. About 6 percent (12 people out of 210) of those who responded have worked with BSL 2 organisms in the last two years, according to the survey. Most of the work used human cell lines, which do not cause disease on their own, but require additional precautions as they can potentially be infected by human pathogens. Other work used mice, which requires approval from an institutional review board in a university setting. One person claimed to work with pit vipers, while another claimed to be working on an influenza detection system. Based on the survey, it is unclear what work was actually done and where it took place. DIYers should be aware of the risks involved in working with potential pathogens and adhere to the BSL lab standards.

As time progresses, it is almost certain that the community will become more technically adept. However, the results from the survey strongly suggest that the threats reported in news headlines have little grounding in reality. These articles unjustifiably amplify fears among the public and policy community about the immediate risks associated with DIYbio.



WHAT SORTS OF EXPERIMENTS HAVE YOU DONE IN THE LAST TWO YEARS?



Myth 3: DIYers are incapable of contributing to biotechnology

Reality: Though academic astronomers have set a precedent of including amateurs in scientific discovery, biology journals have doubted the DIY movement's capability of contributing to biotech. *Nature Biotechnology* summed up one view in a 2009 quote: "This is a joke, right?"[15] Despite the skepticism, DIYers have already begun to make contributions as the tools of biotechnology have become available.

In one example, protein engineers crowdsourced the computationally difficult prediction of protein structures through an online game called Foldit. The "game" has so far garnered five publications in top science journals. In one, the authors asked online gamers to predict the shape of an HIV enzyme that scientists had been struggling with for a decade. The gamers solved the problem within three weeks.

While most DIYers are still learning the essentials of biotechnology, many already have expertise in electronics and access to rapid prototyping tools like 3D printers and laser cutters. As such, DIYers have succeeded in producing inexpensive alternatives to expensive biotechnology equipment. A professional PCR machine, for example, a lab staple used to copy DNA, costs more than $2,000. DIYers developed their own kit version that only costs $600. Called the OpenPCR, the schematics are openly available online.[16]

DIYers continue to produce less expensive alternatives to premium lab products. About 40 percent of respondents said they had built some of their lab equipment themselves. Though perhaps not strictly "scientific discovery," such innovations are transformative and indirectly aid research by making equipment more available. The reduced price opens the technology not just to DIYers, but to educators and students.

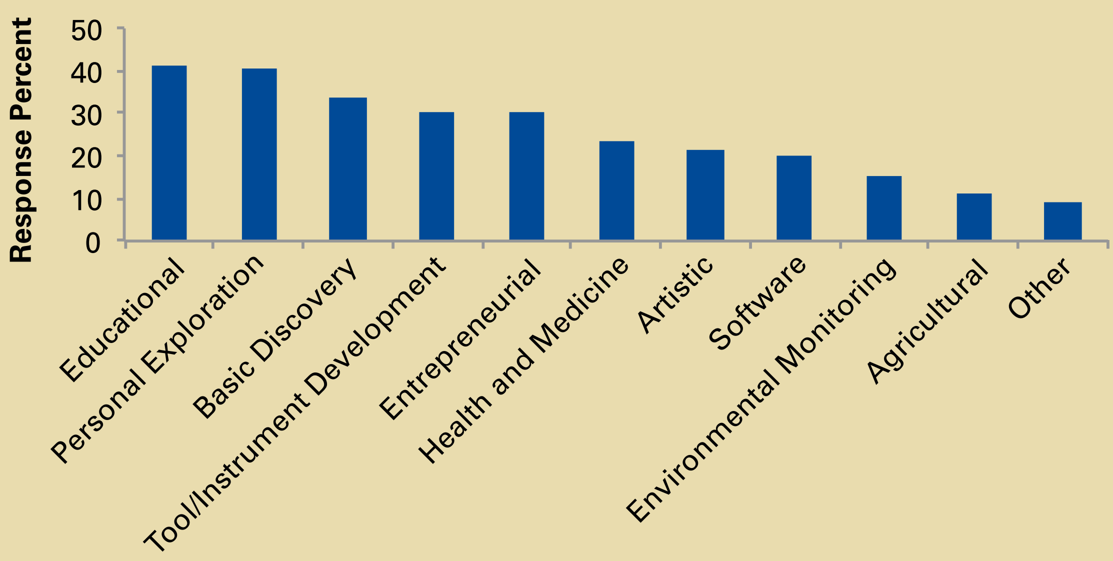
DIYers have also attracted private capital. In 2012, three Dutch DIYers won $52,000 in a design competition for developing a handheld malaria diagnostics device intended for the developing world. The team now has a startup company called Amplino.

More recently, DIYers have sought funding from the public. In June, a group of DIYers in California raised almost $500,000 in 30 days on the crowdfunding website Kickstarter for a project to develop a bioluminescent plant. The fundraising model rivals the amounts given by traditional grants, is more expeditious, has a lower overhead rate compared to universities, and has the potential to create a new avenue for financing applied biotech research.

It should be noted that while scientists traditionally identify progress with published journal articles, this is not necessarily the case for DIYers. Those in the movement with scientific backgrounds will likely seek to publish in journals. But many come from outside of academia, and therefore, do not view journal publication as a validation of their contributions. Many would just as likely publish their results on blogs and websites.

DIYbio's contribution to biotechnology should be judged in three categories: 1) technical and scientific achievements, 2) new business achievements, and 3) contribution to public awareness and education. DIYers are already showing progress in each of these areas.[17]

HOW WOULD YOU CATEGORIZE YOUR PROJECT? (MULTIPLE CHOICES ALLOWED)



Myth 4: DIYers are averse to government oversight

Reality: Our growing ability to stitch together large sequences of DNA and manipulate more complex combinations of genes raises the fear that biotechnology may one day become too powerful, requiring further limits to access. In 2002, Eckard Wimmer, a geneticist at Stony Brook University, demonstrated how potentially destructive a strand of DNA can be when he recreated poliovirus from gene sequences he had ordered online.[18] Gene synthesis companies have since instituted screens to block dangerous sequences from entering the wrong hands, but the point was made. Not only might individuals bioengineer new epidemics, they could potentially reconstitute epidemics from the past using publicly accessible gene databases. For many, the burgeoning DIY community factors as an additional risk. In 2010, the White House recommended no new regulations, but called for "prudent vigilance" as the technology advances.[19] By this, it meant that lawmakers should carefully monitor developments for the appropriate time to instate new safety regulations. As such, Harvard synthetic biologist George Church has proposed the precautionary measure of requiring licenses for DIY synthetic biologists.[20]

On the other hand, some have argued that increased oversight could drive DIYers underground. That is, rather than comply, many might simply do their work in secret.

Such a situation would multiply rather than mitigate the risks.[21]

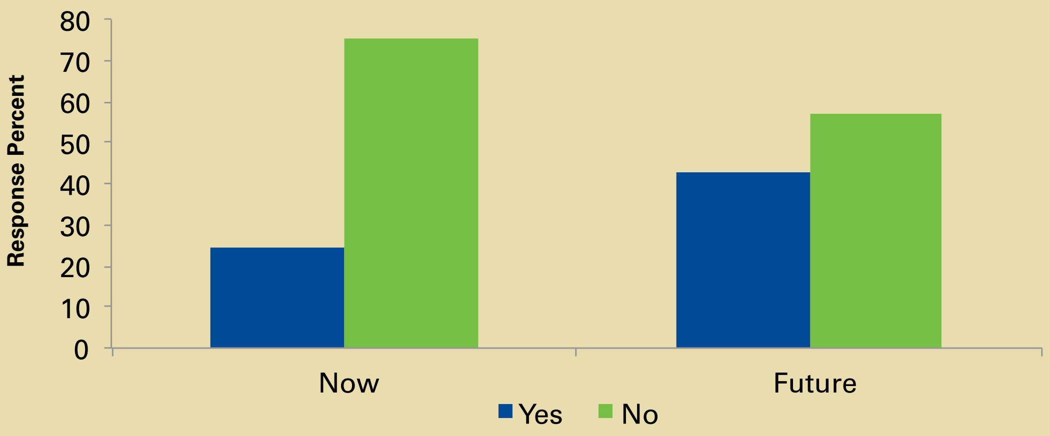
The DIYers themselves have largely been absent from the oversight conversation. The underlying assumption has been that they uniformly stand against it. In fact, DIYers are aware of the risks, and they themselves are split over the question of oversight. According to the survey, 75 percent of DIYers believe there should be no additional government oversight now. But when asked about oversight in the future that number falls to 57 percent.

The explanations given by the 43 percent who believe in future oversight divide into three categories: 1) they believe that DIYbio should be treated no differently from academic or industrial labs; 2) they believe that organisms and equipment should be regulated rather than labs and individuals; 3) they believe that regulation should depend on the state of the technology. One DIYer, for example, recommended new regulation if the technology evolved so the poliovirus genome could be synthesized at home.

Policymakers should be encouraged that DIYers are already themselves considering the issue of oversight. In the absence of a national regulatory structure dedicated to DIY projects, the community has proactively begun to devise it own codes. DIYbio.org in conjunction with the Wilson Center's Synthetic Biology Project has also established the "Ask a Biosafety Expert" service, a free service for DIYers to pose their safety questions to biosafety professionals and members of the American Biological Safety Association.[22]

Policymakers should work with the community to shape a more comprehensive policy, delineating when DIYers should self-regulate and when the government should intervene.

SHOULD THERE BE GOVERNMENT OVERSIGHT OF DIYBIO NOW OR IN THE FUTURE?



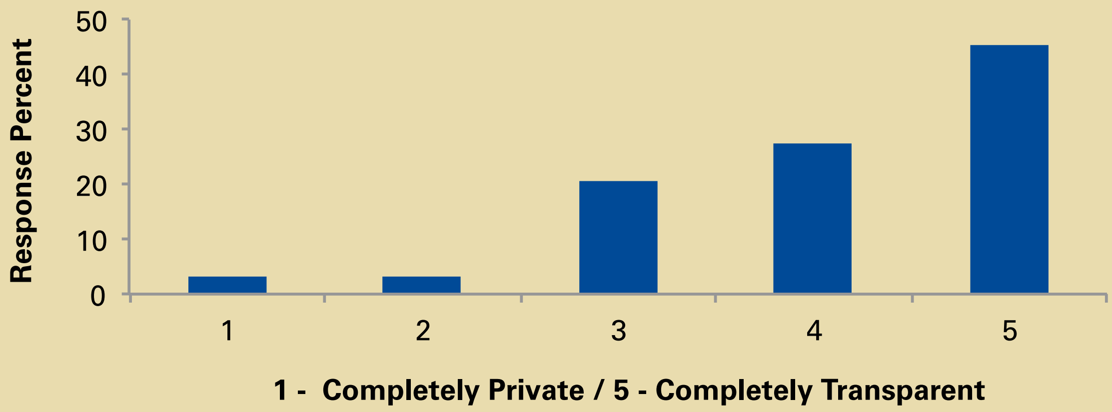
Myth 5: DIYers lack the comprehension to do biotech ethically

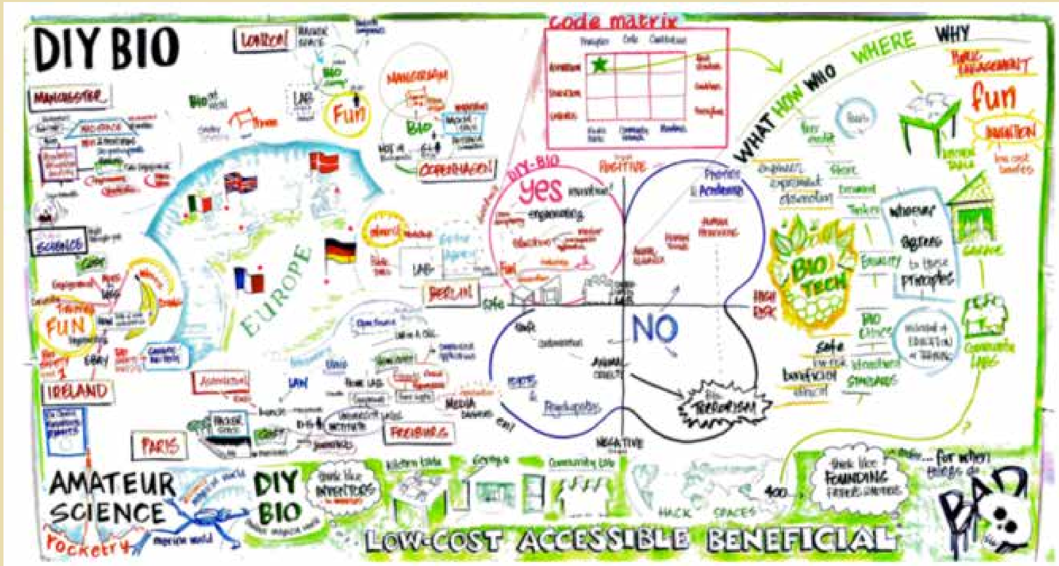
Reality: "People overestimate our technological abilities and underestimate our ethics," Jason Bobe, one of the founders of DIYbio.org, told *The New York Times* in 2012.[23] Because DIYers come from all walks of life, may lack formal education, and are not overseen by institutional review boards, the policy and science communities fear that they may be more likely to cross ethical boundaries.

Indeed, DIYers lack formalized checks on their work, but a number of informal checks do exist. Most DIYers work in community spaces that require BSL1 lab conditions and do not allow animal use. This low biosafety level precludes many of the ethical questions related to animal experiments or the use of pathogens.

In addition, most DIYers advocate transparency in their work. The survey asked respondents their feelings about transparency and sharing their work on a scale from 1 to 5 (1 being completely private and 5 being completely transparent). 73 percent of respondents selected 4 or 5, that is, almost all of them favored openness in their work. Only 6 percent preferred privacy.

WHAT ARE YOUR FEELINGS ABOUT TRANSPARENCY AND SHARING YOUR WORK?





*Graphic interpretation of European DIYbio coding workshop held in London, 2011

Transparency is important to the cultural fabric of the DIY community. As DNA sciences advance, a number of ethical questions arise over privacy and the right to sequence another's DNA. Beyond the DIY community, society at large is contending with ethics and privacy issues around DNA.[24] At this point in the debate, transparency is a healthy policy. If an individual is perceived to be working unethically, this openness allows other members and stakeholders to step in and object.

Finally, the DIYbio community, primarily the community labs and established regional groups, has already developed a shared code of ethics.[25] In 2011, The Wilson Center and DIYbio.org brought together the DIYbio leadership in Europe and United States to establish their own codes of ethics. Both codes are remarkably similar. Certainly, not every DIYer has signed onto them. However, the first steps have been taken, and these codes help strengthen the culture of responsibility burgeoning in DIYbio.

DIYbio Code of Ethics
Draft from the U.S. delegates
July 2011

Open Access
Promote citizen science and decentralized access to biotechnology.

Transparency
Emphasize transparency, the sharing of ideas, knowledge and data.

Education
Engage the public about biology, biotechnology and their possibilities.

Safety
Adopt safe practices.

Environment
Respect the environment.

Peaceful Purposes
Biotechnology should only be used for peaceful purposes.

Tinkering
Tinkering with biology leads to insight; insight leads to innovation.

DIYbio Code of Ethics
Draft from the European Delegation
May 2011

Transparency
Emphasize transparency and the sharing of ideas, knowledge, data and results.

Safety
Adopt safe practices.

Open Access
Promote citizen science and decentralized access to biotechnology.

Education
Help educate the public about biotechnology, its benefits and implications.

Modesty
Know you don't know everything.

Community
Carefully listen to any concerns and questions and respond honestly.

Peaceful Purposes
Biotechnology must only be used for peaceful purposes.

Respect
Respect humans and all living systems.

Responsibility
Recognize the complexity and dynamics of living systems and our responsibility towards them.

Accountability
Remain accountable for your actions and for upholding this code.

Myth 6: DIYers risk accidents and environmental release of genetically modified organisms

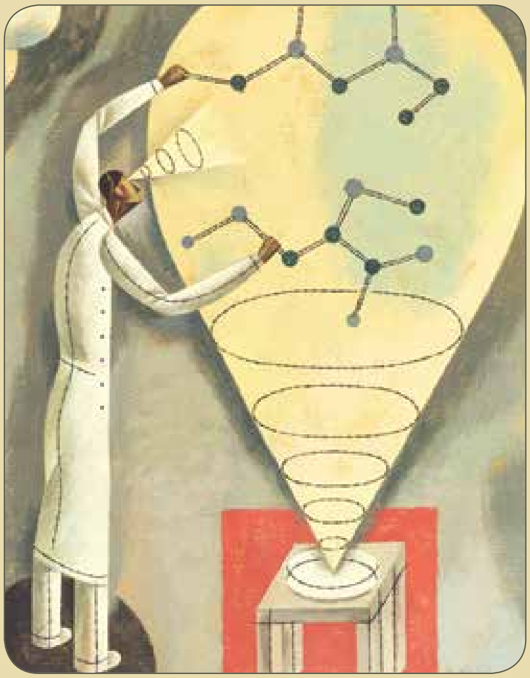
Reality: DIYers working with synthetic biology and genetic engineering enter into disciplines already familiar with controversy. The global public is divided about the consumption of genetically engineered foods, and advocacy groups like the ETC Group and Friends of the Earth have called for a "moratorium on the release and commercial use of synthetic organisms, cells, or genomes" until certain principles of oversight are met.[26] A large part of the controversy revolves around environmental release, the concern that a gene or a genetically modified organism will get into the ecosystem and threaten the environment or public health. The fact that a growing number of DIYers are entering the discipline multiplies the risks. "There could be thousands of people making millions of invasive species," said one delegate at the 2013 Cambridge, UK, academic conference titled "How will synthetic biology and conservation shape the future of nature?"[27]

The crowdfunded bioluminescent plant project described in Myth 3 is one project that presents environmental release concerns. Upon achieving the project's goal, the group, made up of two PhD scientists and a masters of business administration graduate, has offered more than 6,000 funders their own transgenic seeds to grow at home. By inserting the novel genes using a gene gun, these seeds escape regulatory oversight and could be planted anywhere in the United States. In addition the project plans to distribute kits which will allow backers to transform and insert their own novel genes. These kits, however, utilize agrobacterium which is regulated[28], and therefore anyone receiving one of these kits may be required to obtain a permit from the U.S. Department of Agriculture, a process few people outside of agribusiness know about or understand. Many are eagerly watching how this project will play out—whether the team will be able to achieve its scientific goals, and the response to individuals obtaining, growing, and releasing bioluminescent plants.

Still, at this juncture, where so few DIYers are using sophisticated synthetic biology, the risks of a hazardous environmental release remain low. In the future, when more DIYers begin bioengineering sophisticated constructs in a wider variety of organisms, a number of considerations should be made. Boundaries between many home labs and group labs may be porous. Some 38 percent of respondents work in multiple places. The data suggests that an experiment performed at one lab might be continued at another. Some individuals carry parts of their experiments back and forth, and an accidental spill while in transit is possible. Currently, such a spill might seem scarier to onlookers than it actually is. Passing materials between labs poses little safety risk as long as the labs remain BSL 1 facilities. Risks however do arise if labs open BSL 2 facilities (designed for pathogens that pose a moderate risk). In the future, DIYers may have to set stricter safety measures about transporting their experiments.

Another concern revolves around how DIYers dispose of lab waste. As is standard lab practice, community labs universally contract with biological waste disposal services. Many respondents working with bacteria and yeast sterilize their materials with bleach before disposal. Some 4 percent (8 out of 212) of respondents dispose of waste from their DIYbio work at university labs. Without explicit permission from the university's lab management, this may raise issues over biosafety, proper waste management, and the university's ability to track lab activities. In addition, transporting waste from one location to another without proper containers and/or permits could raise additional concerns.

Based on the survey results, the risk that DIYers presently pose to the environment is low. However, as the technology and DIY community develops, those risks may require reassessment.



Myth 7: Group labs may become unsuspecting havens for bioterrorists

Reality: As part of the FBI's Biological Sciences Outreach Program, an agency effort designed to strengthen the relationship between the science and law enforcement communities, government representatives and some DIYbio leaders have begun a dialogue about safety and security. One recurrent topic during their meetings has been the risk of a nefarious actor seeking to do harm with the tools available at community labs. A number of factors make this scenario unlikely.

First, many DIY community labs have strict rules about lab access. At Brooklyn's Genspace, for example, community lab directors evaluate each new member and their project for safety. In cases where the directors do not have the expertise to evaluate a project, they consult with the lab's safety advisory committee made up of university professors and biosafety officers. In the absence of such a committee, DIYbio.org provides the Ask a Biosafety Expert service, where experts and members of the American Biological Safety Association answer safety questions. If the potential member or project seems suspicious, the nefarious actor may not pass this screen.

Second, directors in most labs approve the reagents and biological materials that are purchased, brought in, and removed from the lab. This serves as another obstacle for a nefarious actor.

Third, because of many labs' policy of openness, it is difficult to remain anonymous in a community setting. Members working beside a nefarious actor would likely notice suspicious activities.

Fourth, the labs lack facilities that would allow a nefarious actor to work safely. If, in fact, someone smuggled a dangerous pathogen into the lab, they themselves would be most at risk.

The final factor is the community labs' already strong relationship with the FBI. At multi-day conferences in 2011 and 2012, government and bureau representatives gathered with prominent DIYers to brief each other on their practices, safety, and security concerns. These meetings served to inform the community about the FBI's interests and inform the FBI agents about the types of work done at community labs. The meetings also built individual relationships between agents and DIYers. Because of these relationships, lab members have contacts within the FBI in the event of suspicious activity. For their part, agents better understand the community and can respond appropriately to false alarms. These meetings have been integral for maintaining the continued level of awareness among DIYers and agents, and should be encouraged to continue.

None of these individual factors may deter a determined nefarious actor who might misuse skills learned in a DIY lab or deceive lab members into misusing their skills, but they do combine to mitigate the threat. That said, this question must continually be revisited as the technology and the DIYbio movement evolves.

Recommendations

1. EDUCATION PLAYS A MAJOR ROLE IN THE DIY MOVEMENT. THIS ASPECT SHOULD BE FOSTERED.

Currently, the U.S. public is unprepared for the ethical questions posed by advancements in biotechnology. According to recent polling, 75 percent of the population has heard little to nothing of synthetic biology and 92 percent have not heard of DIYbio.[29] Meanwhile, U.S. students trail other developed nations in math (ranked 25th) and science (ranked 17th).[30] The emergence of DIYbio, a grassroots movement focused on biotechnology, presents a much-needed public education opportunity.

Some 41 percent of DIYers categorized their lab projects as educational—more than any other category listed. Along with public talks, workshops, and events at fairs, community labs host courses on biology and biotechnology for students and the lay public where participants are given the opportunity to perform science experiments under the guidance of instructors at a price point far below other educational institutions. Between 9 and 12 hours of lab education cost $150 to $300. Lab membership and the associated informal peer education cost roughly between $85 to $100 per month.[31] These educational opportunities serve to demystify the science for the lay public.

DIYbio labs also allow for new types of institutional partnerships. One successful example involves the Urban Barcoding Project, a New York City high school competition that encourages students to explore biodiversity using DNA technology.[32] Students compete to find the most compelling sequences within their local environments to win the competition. For example, winners in one competition used DNA samples to study ant diversity in the Bronx. In 2012, Genspace community lab partnered with the Sloan Foundation and Cold Spring Harbor Laboratory to serve as a Brooklyn-based lab for training science teachers and student competitors. The staff at Genspace trained and mentored nearly 50 students as part of the competition. Such partnerships should be encouraged.

As neighborhood DIY groups continue to appear, they may more broadly influence public sentiment about biotechnology. Community labs should be seen as a resource rather than a threat. Academic and educational institutions that lack expertise and laboratory facilities should partner with these groups to perform community outreach and education. Public institutions — including law enforcement and environmental protection and public health agencies — seeking to communicate to the public about biology could reach out to community labs as a partner or venue.

2. DIYBIO MAY SERVE A COMPLEMENTARY ROLE TO ACADEMIC AND CORPORATE RESEARCH.

As DIYers become more sophisticated, corporate and academic labs should consider partnerships with them to tap the creative ideas flowing from the movement. Some 28 percent of DIYers already do some or all of their work in an academic, corporate, or government labs.

Just like the scientists behind Foldit crowdsourced solutions to difficult protein-folding problems (see Myth 3), large corporations have begun to crowdsource new ideas from the public through third-party consultants like Innocentive and NineSigma. Academic institutions that lack the space, expertise and equipment for teaching and conducting biotech research might also consider partnering with DIY labs.

At present, DIYbio's greatest strengths are in reimagining new uses or finding less expensive methods for already discovered laboratory science. Corporate research and development departments might foster and support ideas coming from the DIYbio community.

3. BENCHMARKS SHOULD BE SET TO DETERMINE WHEN DIYERS SHOULD SUBMIT TO FURTHER OVERSIGHT.

As biotechnology advances, policymakers and law enforcement agencies face new challenges concerning the safe and secure use of the technology. Rather than debating the potential risks posed by the DIYbio community, policymakers should partner with the community to develop a set of reasonable benchmarks for the prudent moment to change government oversight of amateur biotechnology, including developing positive incentives for safe practice. Some factors might include the state of the technology, DIYers' access to it, and the size of the community of practitioners.

DIYers represent a diverse community that can act as a bridge between the general population, industry, and academia.

Policymakers should invite the community to contribute to policy development processes, actively seeking their views in public consultations, and enable their participation in relevant international processes. As discussed in Myth 4, the DIY community is split over the question of oversight. It is a sensitive topic that should be broached in an inclusive and open way.

4. SET A HORIZON WHEN DISCUSSING RISKS.

The policy debate over risk has been crippled by speculation about DIYers' future capabilities. Though fascinating reading in the media and journals, it is caustic to policy debates and creates fear instead of insight. Rather than panic over DNA assassins and secret DIY flu engineers, policymakers should take a sober look at the projects DIYers are working on now, consider their capabilities and compare that with the current state of the technology, limiting their projections to a five-to-seven-year horizon.

There is considerable debate about what will be possible in the near future in the fields of gene synthesis and sequencing. It may be fair to say that sequencing genes will only get cheaper. It is unclear, however, how long it will take before DIYers are capable of synthesizing genes on inexpensive gene printers rather than outsourcing to mail order synthesis companies, which until now has been a chokepoint in the distribution of dangerous sequences. The time when anyone can synthesize long segments of DNA may be a watershed moment for the oversight debate.

5. GOVERNMENTS SHOULD FUND NETWORKS OF COMMUNITY LABS.

One of the major opportunities and current focuses of the DIYbio community is education. The United States has fallen behind the rest of the world in math and science education, and primary school education curriculums contain little to no biotechnology. Community laboratories are beginning to fill that void by providing courses and hands-on experience in the fields of biotechnology and synthetic biology. More importantly, they are providing the impetus to inspire the next generation of scientists, engineers, and innovators. They also can provide opportunities for universities and community colleges that may not have labs equipped for synthetic biology and other biotechnology experiments. For example, in 2011 Genspace provided the lab space, equipment, and advisory role for an iGEM team consisting of students from Cooper Union and Columbia University.

In its "National Strategy for Countering Biological Threats," the National Security Council states, "From cutting-edge academic institutes to industrial research center, to private laboratories in basements and garages, progress is increasingly driven by innovation and open access to the insights and materials needed to advance individual initiatives."[33] The United States has always viewed itself as a driver of innovation. While no one can say for certain whether the DIYbio movement will spur the next revolutionary technology, potential exists. One of the major challenges for the DIYbio movement, and community laboratories in particular, is acquiring the resources needed to establish and maintain working facilities. Even though the cost of sequencing technologies is rapidly dropping, maintaining a laboratory requires a constant source of financing. Innovative methods and non-traditional fundraising have enabled the DIYbio community to raise funds to operate thus far, but to harness the intellectual power of the DIYbio movement, federal funding agencies should develop metrics and procedures for actors outside the traditional academic or business communities to receive federal grants.[34]

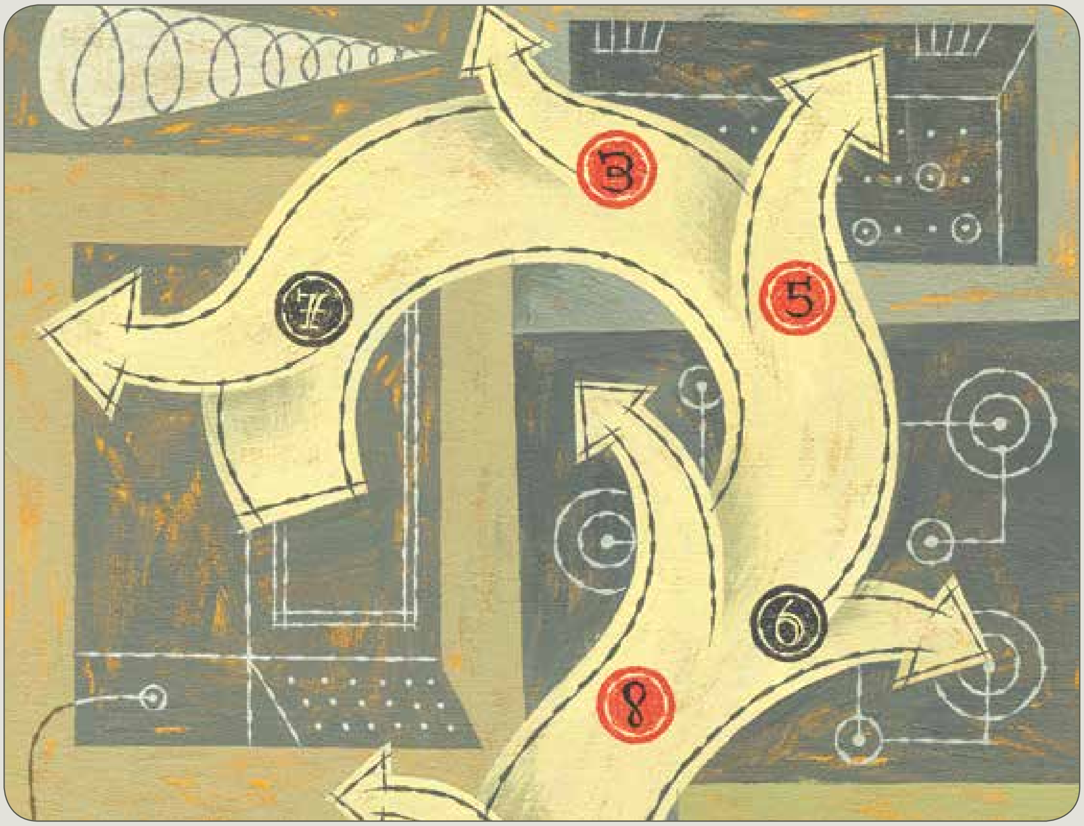
One replicable model may be the recent partnership developed by the municipality of Paris and La Paillasse community lab. To spur entrepreneurship, the city has offered the lab public funding and 900-square-feet of free space in a downtown building for its lab.[35]

Federal funding agencies should encourage partnerships between community colleges and community laboratories in order to approve grants directed towards community laboratories. In addition, seed funding could go towards financing equipment, materials, and training in biosafety. Government could also help source equipment and materials for these laboratories by donating obsolete or unwanted equipment. It can also help build capacity by encouraging federal employees, including biosafety experts, to interact more freely with the DIYbio community.

6. CREATE MORE OPPORTUNITIES FOR INTERACTION BETWEEN DIYERS AND GOVERNMENT.

The results of the survey demonstrate the need for appropriate opportunities to build relationships between the DIYbio community and relevant parts of government. The experience of U.S. DIYers with the FBI highlights the benefits these relationships have in building confidence, increasing transparency, and addressing fears and concerns (see Myth 7). Similar relationships should be developed in all countries where DIYbio groups are found.

If governments invest in bringing groups together and helping them network and share experiences, insights, and ongoing projects, they will have a better idea of what the community actually looks like and what it is doing. This would also provide a unique forum to review critical issues on an ongoing basis. These issues include outreach on the risks and regulations involved in working with pathogens; working with the community to identify suitable boundaries between self-regulation and government action; reassessing any risk the DIYbio community represents to the environment; and reassessing the risk that nefarious actors could misuse community labs to cause deliberate harm. It would also provide a useful conduit to feed contributions from the DIYbio community into relevant international processes.



Conclusions

The DIYbio community is not an anonymous threat to public biosafety and security. Rather, the movement provides a new channel for public science engagement and education and a broad opportunity for economic and scientific innovation. Though still in the early phases of development, the community has already shown promise in all these areas.

The negative portraits drawn by policymakers and media mismatch the survey data. DIYbio shows a well-networked community that is aware of the risks and ethics related to biotechnology. The data also shows that DIYers are almost exclusively working with BSL 1 organisms, rather than the pathogens imagined in the press. At present, very few DIYers are actually engineering genes, but that number stands to grow as the technology becomes easier and more reliable.

It is in the interest of academia, industry, and government to foster these communities through grants, access to equipment, and shared expertise.

As the DIYbio movement grows and becomes more technically adept, greater governance may be required. However, contrary to news reports, the community is already actively engaged in developing codes of conduct, developing safety protocols, and discussing the various regulations that may affect it. To harness this community's potential to provide biotech innovation, education, and awareness, policymakers should treat the community as a valued stakeholder within the larger biotech community and include it in future policy discussions.

Methods

The survey questions were designed by Daniel Grushkin, with input from Todd Kuiken of the Synthetic Biology Project and Jason Bobe of DIYbio.org. The survey was conducted online between January and March 2013. Respondents were contacted through the DIYbio.org message board, online forums at hackerspaces and community labs, and direct contact with DIYbio community leaders.

A total of 359 people responded to the survey, estimated at between 8 and 12 percent of the entire community. The size of the DIYbio community is estimated at between 3,000 and 4,000 people, based on the DIYbio subscriber base and the estimates of community labs.

Respondents were asked to answer 26 questions, including multiple choice, fill-in-the-blanks, and short answer. The survey collected information on demographics and details related to types of and locations of the DIY experiments being carried out by the respondents.

As a reward for their participation, one respondent was randomly selected to receive an OpenPCR.

Survey responses were then compiled and independently analyzed without any knowledge of individual identities. For the purposes of this report, the number of subjects who responded to a specific question was used as the denominator for the percentage calculations.

Appendix 1:

DIYBIO COMMUNITY SURVEY

For access to the raw survey data please visit: www.synbioproject.org/library/publications/archive/6668/

Appendix 2:

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The **Synthetic Biology Project** was established in August 2008 at the Woodrow Wilson International Center for Scholars. The Project aims to foster informed public and policy discourse concerning the advancement of synthetic biology—an emerging interdisciplinary field that uses advanced science and engineering to make or re-design living organisms, such as bacteria, so that they can carry out specific functions. Synthetic biology involves making new genetic code, also known as DNA, which does not already exist in nature.

Work of the Synthetic Biology Project is supported by a grant from the Alfred P. Sloan Foundation.

For more information about the Project visit: www.synbioproject.org

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