The highly specialized nature of scientific research has erected substantial barriers between professional scientists and the laity, who have become distanced from the process of discovery. The Do-It-Yourself Biology movement seeks to remove these impediments, with community laboratories serving as vehicles for public engagement and participation in scientific inquiry. We describe our experience establishing and maintaining the BUGSS community lab in Baltimore. While each community lab is distinct in its structure, culture, and programming, we hope that this review of our experience will serve as a resource to inform those who seek to understand this growing movement and those who plan to establish their own community labs.

INTRODUCTION

The practice of science was once the realm of amateur practitioners, and those without formal scientific training, such as Antonie van Leeuwenhoek, Joseph Priestly, and Benjamin Franklin, have made major contributions. However, the scientific research process has become increasingly professionalized over the last century, allowing few opportunities for people outside the establishment to participate. The specialized knowledge, sophisticated equipment, and rigorous training that scientists undergo have resulted in tremendous scientific advances but have also built barriers between scientists and the public, who indirectly funds their research. Although the proliferation of films and popular science publications bear witness to the public’s continued interest in science, few venture into one of the laboratories where modern biology research occurs. However, the DIY-Bio (do-it-yourself biology) movement seeks to remove obstacles that prevent participation by hobbyists, small entrepreneurs, and curious individuals. DIY-Bio encompasses a diverse set of activities (reviewed in 5 and 9), all involving lab research outside of traditional settings. DIY-Bio has established a parallel infrastructure, including a Google group and listserv (http://diybio.org), journal (www.oreilly.com/biocoder/), and code of ethics (http://diybio.org/codes).

Although some DIY-biologists practice at home in makeshift laboratories, community labs (biohacker spaces) are increasingly common. Community labs are communal spaces that provide shared instrumentation (typically second-hand equipment (10, 12)), reagents, management, and communal projects. Although the physical space and resources are important, equally important is the community itself, which provides the collective expertise to engage in meaningful projects. For example, on a typical night, you may find an artist, an engineer, and a computer programmer huddled over a 3D printer that they have programmed to extrude agar and plant cells into a form that will grow and evolve over time. The collaborations that develop from bringing individuals with varied expertise and backgrounds together is something that many established scientific institutions strive for, but these often happen spontaneously in the community lab environment. While some community projects are meant to test hypotheses, projects such as the plant bioprinting may be initiated for their artistic merit and their ability to develop new biological technology. Community labs generally do not seek to compete directly with academic researchers in inquiry-driven research and instead often focus on the design and manipulation of novel biological systems, including those with practical applications.

Based loosely on technology hackerspaces and drawing inspiration from the synthetic biology community, community labs vary greatly in the types and extent of activities. Some, such as Genspace in New York (www.genspace.org (7)) and Biocurious in California (www.biocurious.org (13)), have robust participation and programming while others fluctuate in the extent of their activities. We are both founding members of the Board of Directors and one of
us (TB) is Executive Director of Baltimore UnderGround Science Space (BUGSS, www.bugssonline.org), a community laboratory in Baltimore, MD, established in 2012. Because the community lab movement is growing and there is a dearth of resources for those establishing community labs, our goal is to share our experience setting up and maintaining a community lab. We discuss our successes, problems, approach to overcoming those problems, and continuing challenges. We respect the great diversity of community lab spaces, and we therefore seek to use our particular experience only as a case study rather than attempting to speak for the movement as a whole.

**SETTING UP A COMMUNITY LAB**

Community labs vary in the scope of their activities. Many labs hold the DIY ethos paramount and therefore concentrate on research projects; for example, the Glowing Plant Project introduced the luciferase gene into Arabidopsis thaliana (2), and Real Vegan Cheese seeks to make dairy products from the cloned casein genes of diverse organisms (3). Some groups retain their strong connection to technology hackerspaces and focus on development of low cost technology such as Open PCR (polymerase chain reaction) (12) or providing broader access to cutting-edge technologies such as CRISPR (clustered regularly-interspaced short palindromic repeats) (11). Yet others focus on education or serve as incubators for biotechnology entrepreneurs. The options are not mutually exclusive, and most spaces support a variety of educational, artistic, or even commercial activities, which may change as different opportunities present themselves. At BUGSS, we focus on both member projects and classes for the public. The educational aspects support the development of member projects by equipping novice DIY-biologists with the skills necessary to function safely and effectively in the lab; this allows us to engage both novices who want highly structured courses and members who seek to pursue independent investigations. While having more than one focus can draw in the greatest number of participants, the institution must retain a level of focus to maintain a coherent identity, enable like-minded people to find one another, and not draw its leadership in conflicting directions.

Traditionally, hackerspaces develop from a core group of people with a shared interest who organize themselves in a democratic, bottom-up manner. The formation of BUGSS, legally organized as a Maryland Non-Profit Corporation, was different. However, we also established a Board of Directors and an Executive Committee. The Board oversees long-term strategic planning and the Executive Committee oversees day-to-day operations. This top-down approach for organizing BUGSS was chosen both to protect the initial financial investment of the founders and to address concerns regarding biological and chemical safety, biosecurity, and the public’s perception of biohacking. Public perception of DIY-biology was foremost in our minds during the formation of BUGSS. Questions are often raised about the risks of bioterrorism or the biological safety of members and the community at large (1,11). In order to allay those fears as well as demonstrate a level of responsibility and seriousness, we generated a number of foundational documents, including Bylaws to establish organizational responsibility and governance, a Membership Agreement to define the rights and responsibilities of all participants, a Safety Policy to set rules for the types of experiments permitted in the space, and lists to delineate what chemicals and biological agents were permissible. As new situations arise, it has been important to have a revision mechanism in place that respects the needs and desires of both members and the broader community.

Having foundational governance documents has also been instrumental in allowing BUGSS to adapt to changes in leadership without the potentially chaotic disruption that could ensue. Initially, the burden of organizing and running the lab was borne by the founders who formed the Executive Committee. However, as the demands on the organization grew, members of the Board of Directors have increasingly stepped in by teaching courses, fundraising, and leading community projects. Currently, BUGSS is undergoing another transition, as funding has been obtained from a local philanthropic organization to hire a staff person. As the needs and demands of the organization have grown, operating on an all-volunteer basis became increasingly problematic, and it was necessary to have a full-time paid staff position to manage the day-to-day activities as well as to develop and implement new programming as directed by the Board.

**REGULATIONS**

Questions often arise as to what regulations apply to community laboratories, and the answer is that there are surprisingly few in the United States. In the absence of federal funding, the presence of employees, or the generation of hazardous waste, most regulation occurs at the state and local level (fire department inspections, zoning restrictions, waste water discharge permits, and business licenses). However, BUGSS adheres to the spirit, if not the letter, of federal agencies such as the Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA). Critical to this effort was the inclusion on our Board of a professional safety consultant with intimate knowledge of the safety and environmental health regulations and practices of the biotechnology industry. Under his guidance, BUGSS developed a chemical hygiene plan, chemical inventory plan, and member safety training protocol that meet the regulatory requirements of state and federal agencies.

Recognizing the need for qualified safety professionals, the DIY-Bio movement has instituted the “ask a biosafety expert” service (http://ask.diybio.org/), which allows members of the community to get answers to questions that may arise. For example, if a person has a question on how to properly
dispose of a live culture or the proper biosafety level for a particular experiment, those questions are answered by a team of professional experts. This is just one example of how the larger DIY-Bio community is proactively addressing safety concerns.

**FUNDING**

Finding a reliable funding model that will cover start-up costs, monthly rent, utilities, and supplies is probably the most significant issue that community labs face. Start-up funding is the first hurdle; several labs, including Biocurious and Counter Culture Labs (https://counterculturelabs.org/) have successfully used crowdfunding venues such as Kickstarter. Others, such as BUGSS, have relied on funds and resources provided by the founders. Regardless of the source of the start-up funds, one essential feature is that there be sufficient resources to enable the organization to survive from inception to the point where income can cover the organization’s operational expenses, which may be months or even years.

Although usually organized as non-profit entities, community labs are businesses. Before we made any financial commitments to starting BUGSS, we held several meetings to gauge local community interest and developed a business plan with cash-flow projections and revenue-generating strategies. Although the reality was a bit different, having a plan allowed us to determine whether we were on the path to sustainability. In retrospect, it would have been useful to have a Board member with business experience to guard against some costly mistakes made early in BUGSS’s development. For example, two areas that we did not pay sufficient attention to were gaining exempt status from the Internal Revenue Service under section 501(c)3 of the tax code and developing timely methods for billing members and collecting payments.

One mechanism that was crucial to our initial success was sharing space; for our first 2.5 years, we substantially reduced our rent by subleasing space from a for-profit startup company, Chesapeake Bioworks, formed by one of us (TB). Sharing space with other hackerspaces, schools, or businesses is a cost-effective way to establish a community lab. However, these arrangements require negotiation of a comprehensive Joint Use Agreement to govern the use of space and equipment and are only likely to be successful if the other entity has an interest in seeing the community lab succeed.

Community labs must then generate operating income. BUGSS generates income through member fees (monthly fees that entitle members to use of the space and a defined amount of supplies and reagents), course fees, donations, and grants. Our most significant sources of operating income are course and membership fees, with substantially reduced rates for students and teachers. While grants are a potentially large source of funding, most philanthropic organizations are reluctant to fund operational expenses and instead restrict their funds to specific programming or activities. In addition, the majority of grant-making organizations can only give money to nonprofits that are tax exempt under section 501(c)3 of the Internal Revenue Code. Obtaining that tax exempt status is an involved task that took us almost a year (although a simpler online application has recently been implemented).

**ACTIVITIES AND PROGRAMMING**

Community labs encompass myriad activities, allowing them to serve diverse audiences. At BUGSS, we focus on talks, courses, and member projects. Talks are the most popular and well-attended activity, and for many individuals, they are the first exposure to the community lab movement. The topics of these public lectures range widely and have encompassed immunology, synthetic genomics, bioinformatics, and bioethics. Given the ideal location of BUGSS within the research-intensive Maryland and Washington DC region, we have been able to host leading scientists from academic, government, and private research institutes; these public lectures offer citizens exposure to a diverse array of topics while simultaneously enabling researchers to explain the broader impacts of their work to the voting public.

Courses allow novices to learn both basic and advanced lab techniques, and most of our class participants are professionals in diverse nonbiology fields, including engineering, law, and art. We intentionally created two scaffolded series of courses (one in molecular and synthetic biology and the other in 3D printing), with the intent of enabling members to build proficiency in lab techniques. Yet, what we find instead is that most individuals take courses sporadically rather than as a way to become fluent with lab skills. We have yet to surmount this problem, which impacts our ability to support independent research projects.

At BUGSS, we feel that the heart of the community lab movement lies in enabling citizens to pursue their own creative projects in biology. Indeed, we have consistent interest from members who seek to develop their project ideas. Membership at BUGSS entitles individuals to use of the space and a limited number of standard molecular biology reagents and chemicals, but members are individually responsible for incurring the costs of their experiments. We encounter two practical limitations. First, our members may lack the technical skills to carry out their experiments. We seek to overcome this by teaching skills in our courses and have found that the courses can serve a secondary function: training student members who can subsequently serve as teachers themselves. Second, project ideas come to us at varying stages of development. Some members have extensively researched their project and have a well-formulated series of experiments. Others are kernels of ideas that require guidance to narrow their scope into feasible projects and to determine what resources are available and what has already been accomplished (or what has previously failed to work). This can be even more challenging when members are
interested in fast-moving fields with extensive literature. To balance the flow of ideas coming in with the time required to convert those ideas into realistic lab projects, we focused on cultivating two projects: using synthetic biology to create a sensor for environmental contamination and bioprinting of plant cells. Because these two projects are consonant with the two focuses of our lab courses, we are able to build expertise within the community to understand and support these two projects. For example, in our synthetic biology courses, we teach members how to assemble BioBrick, standardized vectors that are used to create composite parts (14); in our member project to create a sensor for contamination, we use BioBrick to assemble a lead-sensitive promoter with a reporter gene, ribosome binding site, and terminator to create the synthetic genetic system. We have also just initiated a series of monthly lab meetings that allow the community to come together, receive project updates, and offer feedback on these member projects. Most importantly, we have built small teams that work on each of these projects, allowing us to funnel new members with limited expertise into a community of citizen researchers who are thereby able to make meaningful progress on a finite number of projects.

CONCLUSION

Contrary to the initial perception of DIY-biology as comprised largely of secretive garage hackers, most participants in the DIY-Bio enterprise accomplish their work within community lab spaces (4). The presence of laboratory equipment and the odd working hours can raise questions from the community about what is occurring in the lab space. Are potentially dangerous experiments being conducted? Are illegal drugs being manufactured? Are pathogens being used? However, due to their limited space and communal nature, community labs can actually guard against clandestine activities and enable safety and regulatory oversight of amateur scientists (6, 1, 8). Many community labs also have reached out to the law enforcement community, and early in its development, BUGSS invited representatives from the FBI to present a talk on the DIY-Bio movement and bioterrorism concerns. Both transparency and proactive supervision of experiments will add legitimacy to the community lab movement as well as assuage concerns concerning these unorthodox establishments. Indeed, the bigger impediment to citizen-science spaces may be that they become overly cautious in an attempt to alleviate fears. Community labs will be an important connection between citizen scientists and security and regulatory agencies as they attempt to ensure public safety without overburdening the creativity that flourishes in these spaces.

Community labs also have an important role to play in communication between institutional researchers and the public. Many lessons have been learned from the public backlash to genetically modified foods, which is not always grounded in accurate understanding of the underlying science. As exciting new fields develop on the cutting edge of biology, direct engagement between researchers and citizens at community labs can help to alleviate concerns before they fully develop. This interaction can ensure that there is public support for the application of these new technologies to healthcare and agriculture.

The impetus behind the formation of community labs is not to keep pace with the leading edge of scientific research; instead, for many, the motivation is to do science within a community of diverse expertise. Given the need for top-down leadership and the movement toward having professional staff, the challenge remains to preserve the community lab as a bottom-up, member-driven organization. This demands that the members themselves retain ownership of the organization by equitably sharing the work of mentoring research, maintaining communications and social media presence, and recruiting new members. While this broad participation is challenging to establish and maintain, it is the only path forward for ensuring sustainable growth. It remains to be seen whether community labs will develop into alternative educational institutions, develop innovative products, or contribute to the scientific knowledge base, but they have already opened an avenue back into the scientific research experience for the engaged layperson.

ACKNOWLEDGMENTS

Work at Baltimore UnderGround Science Space was supported by a grant from the R.W. Deutsch Foundation. The authors declare that there are no conflicts of interest.

REFERENCES