FOR LIBERTY AND ACCESSIBLE SCIENCE FOR ALL: BUILDING A BETTER UNDERSTANDING OF U.S. COMMUNITY LABORATORIES AND THE DO-IT-YOURSELF (DIY) BIOLOGY MOVEMENT

by

Yong-Bee Lim
A Dissertation
Submitted to the
Graduate Faculty
of
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in Partial Fulfillment of
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of
Doctor of Philosophy
Biodefense

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A Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

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DEDICATION

In memory of Dr. Fran Harbour – you taught me the steps so I can now dance.

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FOR LIBERTY AND ACCESSIBLE SCIENCE FOR ALL: BUILDING A BETTER UNDERSTANDING OF U.S. COMMUNITY LABORATORIES AND THE DO-IT-YOURSELF (DIY) BIOLOGY MOVEMENT

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The Do-It-Yourself Biology (DIYBio) community is a global movement comprised of citizen scientists, bio-artists, tinkerers, and other individuals exploring and experimenting with biology outside of academic, government, and industry. Since its emergence in 2008, it has drawn the attention of the biorisk community, mainstream media, and the public due to the potential implications it has on the biorisk threat landscape in the United States and across the globe. The biorisk community views the community as a potential threat based on three assumptions in its narrative, including how this community 1) is likely to harbor malevolent intent given its disruptive ideology; 2) can successfully achieve complex scientific projects now that is has access to life sciences technology and protocols; and 3) is the harbinger of a world where anyone, anywhere can obtain life sciences equipment and information. However, the existing literature provides little to no evidence that the assumptions of the biorisk narrative are true. Therefore, this dissertation

seeks to fill this gap by research a large subsection of the Do-It-Yourself Biology (DIYBio) movement known as community labs – shared biology lab spaces that are open to their local community and reside outside of academia, industry, and government spaces. This study used a combination of on-site field observations and interviews with community members and leaders at 9 community labs across the United States. While the ongoing COVID-19 pandemic prevented me from going to all 9 community labs in-person, I observed 7 community labs directly as an active observer and interviewed and recorded a total of 43 community lab members using the video-conferencing tool Skype. With these two qualitative datasets, I generated novel data that provides and unprecedented level of understanding concerning community lab participants in the DIYBio movement in four ways. First, this study provides insights into the **drives** of community founders and members – what motivates founders to start these places, as well as the initial and current motivations for why members participate in these spaces. Second, it provides insights into the **design** of community labs spaces – how these spaces are organized, as well as leadership and financial details. Third, I provide insights on the **degree** to which community labs represent the **democratization** of the life sciences. Fourth, I use these three different data categories to do a biorisk threat assessment using bioterrorism, STS, and ICT literatures to test the assumptions of the biorisk narrative. This study argues that researchers, policymakers, and the DIYBio community itself have lacked a comprehensive characterization of this techno-social phenomenon since its inception in 2008. For scholars of science and technology studies (STS), this study argues that a more comprehensive characterization is necessary to better understand how

DIYBio community labs emerge, grow, and operate in the United States. For policymakers, this study argues that a better understanding of the capabilities and limitations of U.S. DIYBio community labs enhances the policymakers' ability mitigate the risks and maximize the benefits of these unconventional spaces of life sciences learning, experimentation, and innovation. Finally, for the U.S. DIYBio community, this study provides a unique resource for introspection: a snapshot of the similarities, differences, and trajectories of nine community labs across the United States between 2019 – 2020. This study concludes by offering observations and recommendations to address biorisk narrative discrepancies, find ways to build bridges and break silos between these two communities, and improve existing biorisk threat assessments.

CHAPTER ONE - INTRODUCTION

Introduction

The Do-It-Yourself Biology (DIYBio) movement is de-centralized group made up of a global community of biohackers, citizen scientists, science professionals, and amateur biologists. This movement emerged in the 2000's as interest in DIY projects grew, access to life sciences materials, equipment, protocols, and reagents increased, and a large number of life sciences professionals were under-employed or unoccupied during the biotech boom and bust in the mid-2000's.[1] The movement's main goal is to democratize the life sciences – to enable access to life sciences knowledge, equipment, materials, and training for every person in the world.[2] This group seeks to promote life sciences democratization through activities ranging from community outreach and seminar sessions with invited experts to teaching biology skills ranging from pipette use to genome-editing and microbe manipulation.[3]

Since its emergence in 2008, it has drawn the attention of the biorisk community, mainstream media, and the public due to the potential implications it has on the biorisk threat landscape in the United States and across the globe. These biorisk concerns include the accidental release of biological materials into the environment, as well as the deliberate creation or manipulation of pathogens for nefarious ends. In 2010, the

[1] Elliot Roth, "A Guide to DIYbio (updated 2019)," *Medium*, https://thatmre.medium.com/a-guide-to-diybio-updated-2019-abd0956cdf74. Accessed March 16, 2021.
[2] Gigi Kwik Gronvall, "Synthetic Biology: Biosecurity and Biosafety Implications," in Sunit K. Singh and Jens H. Kuhn, eds. *Defense Against Biological Attacks, Vol. 1*, (Switzerland: Springer, 2019), 226.
[3] Lisa Z. Scheifele and Thomas Burkett, "The First Three Years of a Community Lab: Lessons Learned and Ways Forward," *Journal of Microbiology and Biology Education* 17, no. 1: 81 – 85.

Presidential Commission for the Study of Bioethical Issues released a report stating that the DIY science community may create new risks as synthetic biology spreads to unconventional science spaces.[4] In 2012, journalist Carl Zimmer from the New York Times wrote an article quoting renowned biosecurity experts and virologists to make the case that amateur scientists could create mutant flu viruses in garage labs.[5] In 2018, journalist Emily Baumgaertner also wrote a New York Times article that quoted prominent figures in the scientific and biorisk communities to further the idea that the DIYBio community is potentially a ticking time-bomb: the catalyst to either an accidental or deliberate biological disaster waiting to happen.[6]

While the DIYBio community has now grown for over a decade, the dueling narratives concerning the risks and benefits of this movement remain stagnant. The biorisk community continues to perpetuate a narrative that express concerns about the community based off three assumptions, which include 1) is likely to harbor malevolent intent given its disruptive ideology; 2) anyone can accomplish complex scientific tasks if they have the technical equipment and information; and 3) anyone can access the tools, materials, equipment, knowledge, and skills to do biology.[7]

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[4] *New Directions: The Ethics of Synthetic Biology and Emerging Technologies*. Washington DC: Presidential Commission for the Study of Bioethical Issues, 2010.
[5] Carl Zimmer, "Amateurs Are New Fear in Creating Mutant Virus," *The New York Times*, March 6, 2012, https://www.nytimes.com/2012/03/06/health/amateur-biologists-are-new-fear-in-making-a-mutant-flu-virus.html. Accessed March 16, 2021.
[6] Baumgaertner, Emily. "As D.I.Y. Gene Editing Gains Popularity, 'Someone is Going to Get Hurt'," *New York Times*, May 14, 2018, https://www.nytimes.com/2018/05/14/science/biohackers-gene-editing-virus.html. Accessed January 5, 2020.
[7] For examples, see John Wikswo, Stephen Hummel, and Vito Quaranta, "The Biohacker: A Threat to National Security," *CTC Sentinel* 7, no. 1 (2014): 8 – 11; Nicholas Cropper, "CRISPR is Making Bioweapons More Accessible," *American Security Project*, April 29, 2020, https://www.americansecurityproject.org/crispr-is-making-bioweapons-more-accessible/. Accessed February 28, 2021; Rachel M. West and Gigi Kwik Gronvall, "CRISPR Cautions: Biosecurity Implications

In response to these biorisk concerns, the DIYBio community has fought back against these allegations and potential implications through a narrative that emphasizes three main points. First, the community emphasizes the self-governance mechanisms it has created to maximize the benefits while mitigating the risks of amateur exploration in the life sciences. Second, the community notes that its members value life sciences democratization for peaceful purposes, and not for harmful ends. Third, the community highlights how the facilities of the group writ-large are not commensurate with the capabilities, expertise, and skills required to conduct challenging scientific tasks like creating biological weapons in garage labs.[8]

However, even in the present day, these narratives continue to amplify and perpetuate within their respective communities. The siloed nature of these narratives makes it impossible for either group to provide an accurate portrayal of the DIYBio community and its effects on the biorisk threat landscape.

In terms of the biorisk narrative, the community ignores important contributions from the terrorism and Science and Technology Studies (STS) literatures that would help inform their assessment in a more holistic fashion. These factors include 1) understanding the drives for why people participate in the DIYBio community; 2) recognizing how the design of community labs, including tacit knowledge and expertise, as well as organizational, managerial, social, and economic elements factor into the success and

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of Gene Editing," *Perspectives in Biology and Medicine* 63, no. 1 (2020), 73 – 92; and Margaret Talbot, "The Rogue Experimenters", *The New Yorker*, May 18, 2020, https://www.newyorker.com/magazine/2020/05/25/the-rogue-experimenters. Accessed February 28, 2020.

[8] Daniel Grushkin, "Biohackers Are About Open-Access to Science, Not DIY Pandemics. Stop Misrepresenting Us," *STAT*, June 4, 2018, https://www.statnews.com/2018/06/04/biohacker-open-access-science/. Accessed March 16, 2021.

failure of complex scientific tasks and projects; and 3) acknowledging the current market and informational limitations that exist that decrease the degree to which the life sciences are democratized to the public.[9]

This ignorance holds true in the case of the DIYBio narrative as well, but with some different outcomes. The siloed nature of the DIYBio narrative introduces a tendency to underplay the shortcomings of the community. This includes a tendency for the community to exaggerate its capabilities, underemphasize the potential for accidents where amateurs interact with volatile chemicals, and underplay the risks associated with distributed technologies, de-skilling, and future advances in the life sciences.

The ability to assess the relative strengths and weaknesses of these dueling narratives is further hampered by a lack of data on the DIYBio community. What are the drives of DIYBio community lab members to start, join, and continue participating in

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[9] For examples, see Landrain et al. (2013). "Do-It-Yourself Biology: Challenges.", p. 117; Sonia Ben Ouagrham-Gormley and Shannon R. Fye, "Restricted Science," *Frontiers in Public Health* 2, No. 158 (2014): 1 – 3, https://doi.org/10.3389/fpubh.2014.00158; Sonia Ben Ouagrham-Gormley, *Barriers to Bioweapons: The Challenge of Expertise and Organization for Weapons Development* (Ithaca, New York: Cornell University Press, 2014), 17 – 21; Kathleen Vogel, *Phantom Menace or Looming Danger?*, Baltimore, Maryland: Johns Hopkins Press, 2013, Loc 278 of 8781; Harry Collins and Robert Evans, *Rethinking Expertise*, Chicago, Illinois: The University of Chicago Press, 2009, 24 – 27; Michelle L. McGowan, Suparna Choudhury, Eric T. Juengst, et al., "'Let's Pull These Technologies Out of the Ivory Tower': The Politics, Ethos, and Ironies of Participant-Driven Genomic Research," *BioSocieties* 12 (2017), 494 – 519; "About Us: Info and History," *Counter Culture Labs*, https://www.counterculturelabs.org/info--history.html. Accessed March 8, 2021; and Meredith L. Patterson, "A Biopunk Manifesto," *LiveJournal*, January 30, 2010, https://maradydd.livejournal.com/496085.html. Accessed March 8, 2021; Iris Hunger, Jez Littlewood, Caitriona McLeish, Piers Millett, and Ralf Trapp, "Roundtable: The Future of Biothreat Governance," in *Biological Threats in the 21st Century*, London, UK: Imperial College Press, 2016, 431 – 450; Sonia Ben Ouagrham-Gormley and Kathleen M. Vogel, "The Social Context Shaping Bioweapons (Non)proliferation," *Biosecurity and Bioterrorism* 8, no. 1 (2010), 9 – 24; Sonia Ben Ouagrham-Gormley and Shannon R. Fye-Marnien. "Is CRISPR a Security Threat?". In *Defense Against Biological Attacks*, 233 - 251. Springer, Cham, 2019; Kathleen M. Vogel and Sonia Ben Ouagrham-Gormley, "Anticipating Emerging Biotechnology Threats: A Case Study of CRISPR," *Politics and the Life Sciences* 37, no. 2, 203 – 219; and Kendall Hoyt, *Long Shot: Vaccines for National Defense*, Cambridge, MA: Harvard University Press, 2012: Loc 529 – 858.

these spaces? How are these community labs designed along organizational, managerial, operational, social, and financial lines to generate, distribute, and use tacit knowledge and expertise to conduct complex scientific tasks? To what degree are the life sciences democratized in the case of DIYBio? How do each of these considerations (drive, design, and degree of democratization) then show changes in the biorisk threat landscape that is introduced by the DIYBio community?

To answer these questions, I first conducted ethnographic research to gather qualitative observation and interview data at 9 DIYBio community labs based in California, the DC Metropolitan area, New York, and Massachusetts. I gathered this data over the course of March 2019 – April 2020. The combination of this data generated rich data on the drives, design, and degree of democratization associated with these DIYBio community labs. I then used this data to assess how these characteristics of the DIYBio community along these factors compared with what existing terrorism and STS literatures predict as contributing to or hindering biorisk threats.

The purpose of my research is not to prove either narrative as unequivocally right. Rather, my research serves three purposes. First, it adds to the body of literature on the DIYBio community in ways that past research has not – rather than focusing on capabilities, my research gathered novel data on the drives, designs, and enablers and barriers to democratizing the life sciences in the DIYBio context. This research is useful for a broad range of stakeholders, including the biorisk and DIYBio communities. Second, this research adds to the body of literature in STS that looks at how de-centralized communities with amateur participants are helped by technical advances and access to equipment, materials, and information in the life sciences, but continue to face obstacles in performing complex scientific tasks due to tacit knowledge, expertise, and socio-technical barriers like organizational, managerial, monetary, and social factors. Third, this research provides an empirically based analysis of the DIYBio community and its effects on the biorisk threat landscape. This analysis is critical to help inform and shape discussions about the benefits, risks, and policy recommendations associated with the life sciences, emerging technologies, and society.

Overview of Findings

The biorisk narrative is built on three assumptions, including 1) the community displays malicious intent; 2) anyone can accomplish complex scientific tasks if they have the technical equipment and information; and 3) anyone can access the tools, materials, equipment, knowledge, and skills to do biology.

My observation and interview datasets provided me with three different categories of data associated with the DIYBio community lab to test these assumptions. The first data category, called **drive** data, gathered the motives for why founders started a community lab, as well as why members initially joined and currently continue to participate in these spaces. Using this drive data and comparing it to the biorisk assumption of malicious intent in U.S. community labs, my conclusion was community labs do not harbor the propensity for violence necessary to qualify as having malicious intent.

The second category of data, called **design** data, gathered information on how community labs were organized, as well as leadership and financial details. Using this design data and comparing it to the biorisk assumption that anyone can accomplish complex scientific tasks, my analysis was inconclusive. On the one hand, community labs are spaces that naturally create a culture of openness and collaboration and encourage communication between and within groups to do everything for learn and teach new skills to address complex issues like troubleshooting contamination issues. In addition, the leadership in these spaces do try to help create this environment and see to the needs of the project members. However, the large numbers of duties that leaders face in community labs make them difficult at times to approach and unable to necessarily meet the needs of a project when they are too busy. Furthermore, community labs have significant financial limitations that end up creating issues when it comes to purchasing reagents, materials, and equipment.

The third category of data, called **degree of democratization** data, gathered information on how democratized the DIYBio community is based on two factors: market accessibility and information accessibility. When comparing this data to the biorisk assumption that DIYBio indicates a fully democratized rendition of the life sciences, the conclusion was that there are still significant organizational, temporal, legal, tacit knowledge, communal, and technical barriers that exist which, in turn, limit the degree to which DIYBio is democratized.

The implications of the findings of this study are that, at the present time, the U.S. DIYBio community lab threat is currently over-exaggerated by the biorisk community.

Given a myopic focus on technical capabilities and explicit knowledge, it would be helpful for the biorisk community to reassess its assumptions and expand its existing threat assessment analysis to include additional considerations like motivations, organizational components, and socio-technical components derived from the bioterrorism and STS literatures.

Methodology

To examine my research questions, I first examined the current dominant narratives from two communities siloed from each other: the biorisk community and the DIYBio community. I then examined the narrative elements and researched the terrorism and STS literatures to elucidate the roots of the assumptions that underpin each narrative. I then uncovered the types of data (the drives, design, and degree of democratization associated with community labs) that is most salient for understanding how the DIYBio community impacts the biorisk threat landscape.

To gather data on the drives, design, and degree of democratization associated with community labs, I gathered two different types of data – observation and interview data. In terms of the observation data, I collected and recorded photos, videos, and short-hand notes in a diary in the field. I then wrote longer and more comprehensive observation data notes for 84 events I attended in person over 55 on-site visits at 8 DIYBio community labs. In terms of the interview data, I conducted, recorded, and transcribed individual interviews with a total of 43 DIYBio community lab members, leaders, and founders across all 9 sites through the Microsoft video chat platform Skype.

I then transferred, collated, and coded the data from both the field observations and interviews through the qualitative data analysis software NVivo. I then compared the patterns and themes that emerged from the data which dealt with DIYBio drives, design, and degree of democratization. I then used this data to conduct a risk assessment on how the characteristics of the DIYBio community along these factors of drive, design, and degree of democratization compared with what existing terrorism and STS literatures predict as contributing to or hindering biorisk threats.

Dissertation Organization

This dissertation proceeds as follow. In Chapter 2, I provide a history of the rise and current state of the DIYBio community, analyze the biorisk and DIYBio narratives and elucidate their underlying assumptions and shortcomings through the consideration of terrorism and STS literature, and discuss why the narrative stand-off is problematic. This chapter also presents my analytical framework on leveraging the predictions of terrorism and STS literatures to determine the changes in biorisk threats that DIYBio community labs present given their drives, design, and degree of democratization. Chapter 3 summarizes the history, activities and characteristics of the community labs researched in this dissertation, as well as describing the methodology for this dissertation.

Chapters 4 – 6 are my analysis chapters for this dissertation. In Chapter 4, I use the bioterrorism literature to highlight two elements of drive that increase the likelihood of nefarious biological weapons research and use by non-state actors – a transformative ideology and a desire to achieve this transformation through violence. I then compare the drives associated with bioterrorism with the community lab observation and interview data. I then assess how community lab drives affect the biorisk threat landscape.

Chapters 5 and 6 use the STS and emerging technologies literature to highlight elements of design (Chapter 5) and degree of democratization (Chapter 6) that enable or hinder the successful accomplishment of complex scientific tasks and projects. I then compare the design and degree of democratization considerations associated the STS literature with those from the DIYBio community lab observation and interview data to assess how DIYBio community lab design and degree of democratization affect the biorisk landscape.

Lastly, I conclude my research in Chapter 7. First, I offer a brief overview of how community labs operated during the COVID-19 pandemic. Second, I summarize the major findings from this dissertation and delve into the implications of the findings of this dissertation research. Third, I offer recommendations for future improvement in this area of study, including 1) incorporating motivational and socio-organizational components to the threat assessment model to generate a more holistic approach that is less likely to generate false positives, 2) finding ways to build bridges between the biorisk and DIYBio communities, and 3) building in DIYBio community members into future threat assessments as subject matter experts in the field. Finally, I offer recommendations for areas of future research, including a deeper understanding of the open science platform Just One Giant Lab (JOGL), understanding DIYBio movement directions and potential community splintering, and doing research on ongoing efforts to expand access to reagents and materials through spaces like Open Bioeconomy and through initiatives like the Free Genes Project.

CHAPTER TWO – THE PROMISE AND PERIL OF DIYBIO?

Introduction

"The era of garage biology is upon us."[10] With these words, Rob Carlson launched the opening salvo in a debate that has raged for the past 15 years. The future that Rob Carlson advocated was one where the average citizen could gain life sciences skills, technology, and knowledge both cheaply and easily. These empowered citizens would learn to program bacteria and plants, produce proteins and other desirable compounds, and even run their own personal life sciences projects with only a little study and elbow grease. In short, the life sciences would no longer be confined within the ivory towers of academia, industry, and government.

Carlson's 2005 prediction proved to be more than empty words. Since 2008, a global community of life sciences practitioners collectively known as Do-It-Yourself Biology (DIYBio) have emerged. This community, estimated to have between 2000 – 4000 members throughout the globe, is composed of individuals and groups operating both independently and collectively.[11] Its members include "a broad mix of amateurs,

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[10] Rob Carlson, "Splice It Yourself," *Wired*, May 1, 2005. https://www.wired.com/2005/05/splice-it-yourself/. Accessed January 3, 2020;

[11] See Günter Seyfried, Lei Pei, and Markus Schmidt, "European Do-It-Yourself (DIY) Biology: Beyond the Hope, Hype and Horror," *BioEssays* 36, no. 6 (2014): 548 - 551, https://doi.org/10.1002/bies.201300149;
"Biohackers of the World, Unite," *The Economist*, September 4, 2014, https://www.economist.com/technology-quarterly/2014/09/04/biohackers-of-the-world-unite. Accessed January 4, 2020.

enthusiasts, students, and trained scientists" who "focus their efforts on using…technology to create art, explore genetics, or simply to tinker."[12]

A critical factor that contributed to the emergence of this community is how life sciences technology, materials, equipment, and information have become democratized. In this context, democratization means a phenomenon or circumstance where something historically confined to a small group of people or populations becomes more accessible to a wider range of people.[13]

In the case of DIYBio, democratization of the life sciences refers to two separate phenomena. The first is that the tangible elements of life sciences advances, such as equipment, reagents, and materials, are disseminated and available to communities outside of the historically typical actors in this space: scientists in academia, industry, and government. This is of note following the biotech bust of 2008, when many small biotech labs went bankrupt and flooded the second-hand market with large amounts of equipment. Donations, second-hand markets, and online purchases and repositories are now allowing curious and motivated amateur scientists, artists, and other interested parties around the world to purchase and explore the use of these tangible elements for their own purposes.[14]

The second is that the intangible elements of life sciences advances, such as visual skill transfer and de-skilling, are making it easier for laypeople to learn skills and try their

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[12] Daniel Grushkin, Todd Kuiken, and Piers Millet, *Seven Myths and Realities about Do-It-Yourself Biology,* Washington DC: Wilson Center, 2013, 4.
[13] Gigi Kwik Gronvall, "Synthetic Biology: Biosecurity and Biosafety Implications," in Sunit K. Singh and Jens H. Kuhn, eds. *Defense Against Biological Attacks, Vol. 1*, Switzerland: Springer, 2019, 226.
[14] Elliot Roth, "A Guide to DIYbio (Updated 2019)," *Medium*, February 17, 2019, https://thatmre.medium.com/a-guide-to-diybio-updated-2019-abd0956cdf74. Accessed February 28, 2021.

hand at life sciences research and projects. Visual media online through public platforms like YouTube and specialized platforms like the Journal of Visualized Experiments provide step-by-step visual and print instructions and demonstrations to conduct anything from basic laboratory skills like pipetting and measuring reagents to performing whole protocols like gel electrophoresis, genotyping, bacterial transformations, and 16S rRNA sequencing.[15] Deskilling is also apparent in the life sciences with the advent of automated, push-button technologies that DNA sequencing and synthesis machines, as well as machines like the OpenTrons OT-2 Robot: a programmable robot that automates the pipetting process.[16]

In the present day with this backdrop of democratization, the DIYBio community has sought to expand its network and activities. Some members envision a world beyond simply basic life sciences activities and playful tinkering. These ambitious members strive to discover new medicines, harness microbes to sequester carbon and address climate change concerns, grow novel building materials, and even build initiatives to help

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[15] For examples, see Eppendorf, "How to Pipette Correctly – A Short Step-By-Step Introduction into Proper Pipetting," *YouTube*, February 27, 2017, https://www.youtube.com/watch?v=QGX490kuKjg. Accessed February 28, 2021; Carolina Biological, "What Glassware Should You Choose?," *YouTube*, April 17, 2014, https://www.youtube.com/watch?v=IIGOzlQOqo0. Accessed February 28, 2021; Bio-Rad Laboratories, "Agarose Gel Electrophoresis," *YouTube*, October 11, 2012, https://www.youtube.com/watch?v=vq759wKCCUQ. Accessed February 28, 2021; Linda Doan and Edwin S. Monuki, "Rapid Genotyping of Mouse Tissue Using Sigma's Extract-N-Amp Tissue PCR Kit," *Journal of Visualized Experiments* 11 (2008): e363, https://doi.org/10.3791/636; "Bacterial Transformation," *Journal of Visualized Experiments,* https://www.jove.com/science-education/10574/bacterial-transformation. Accessed February 28, 2021; and "16S rRNA Sequencing: A PCR-based Technique to Identify Bacterial Species," *Journal of Visualized Experiments*, https://www.jove.com/v/10510/16s-rrna-sequencing-pcr-based-technique-to-identify-bacterial. Accessed February 28, 2021.

[16] For examples, see "Whole-Genome Sequencing," *Illumina*, https://www.illumina.com/techniques/sequencing/dna-sequencing/whole-genome-sequencing/human.html. Accessed February 28, 2021; Hudson Robotics," Gene Assembly," *Hudson Robotics*, https://hudsonrobotics.com/products/applications/gene-assembly/. Accessed February 28, 2021; and "Meet the OT-2," *Opentrons*, https://opentrons.com/ot-2. Accessed February 28, 2021.

eliminate world hunger.[17] These members may work independently or work collaboratively in community labs – dedicated labs, typically in unconventional spaces like rental office spaces and even sheds, created by members through pooled resources. A prominent example of these types of activities includes the Open Insulin project, which brings together a global network of DIYBio members to offer an alternative to spiking insulin costs: an open-source protocol for communities to grow, produce, distribute, and administer their own insulin.[18]

There are also members of this community that are interested in improving and enhancing their physical and cognitive capabilities through activities that are commonly referred to as "biohacking".[19] These members use wearable technologies like a wrist-worn FitBit or a finger-worn Oura Ring to accomplish this task. These wearable technologies allow users to passively gather basic biometric data, including heart rate and temperature. These technologies also function as a pedometer to gauge the number of steps a person takes per day. For more advanced models, companies develop algorithms to help calculate the amount and difficulty of exercise a person does in a day as well as how well-rested the user is. The goal for these self-identified biohackers is to use the data from wearable technologies to optimize their diet, improve their mood, and find ways to

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[17] Ibid, 4.

[18] Grant Burningham, "The Price of Insulin Has Soared. Biohackers Want to Fix It," *Time*, October 24, 2019, https://time.com/5709241/open-insulin-project/. Accessed January 3, 2020.

[19] Bernard Marr, "What's Biohacking? All You Need to Know about the Latest Health Craze," *Forbes*, February 26, 2021, https://www.forbes.com/sites/bernardmarr/2021/02/26/whats-biohacking-all-you-need-to-know-about-the-latest-health-craze/?sh=257816b85d76. Accessed February 27, 2021.

enhance their performance in areas such as work efficiency, mental focus, and physical fitness.[20]

Others consider biohacking to involve more active modifications. Such modifications include implanting magnets, computer chips, or wireless hard drives into the body. These modifications result in outcomes which are novel (for example, the ability to physically feel magnetic fields), convenient (for example, the ability to unlock personal computers and digital locks through radio-frequency identification [RFID] devices) and may blur the lines between man and machine (for example, the PegLeg is a biohacker project where peoples surgically implant a subdermal wireless router and hard drive to create local wireless networks).[21]

Biohacking can also refer to the deliberate manipulation of a living organism at the genetic level. The goal of this form of biohacking is to either introduce desirable or eliminate undesirable traits in a target micro-organism.[22] This form of biohacking is referred to more formally as genome editing in traditional academia, industry, and government. While this technology has gained a lot of attention in recent years, it has existed in various iterations since the 1970's.[23]

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[20] Elliot Roth, "A Guide to DIYbio (Updated 2019)," *Medium*, July 14, 2019, https://medium.com/@ThatMrE/a-guide-to-diybio-updated-2019-abd0956cdf74. Accessed January 3, 2020.
[21] Sigal Samuel, "How Biohackers are Trying to Upgrade their Brains, their Bodies – and Human Nature," *Vox*, November 15, 2019, https://www.vox.com/future-perfect/2019/6/25/18682583/biohacking-transhumanism-human-augmentation-genetic-engineering-crispr. Accessed January 3, 2020.
[22] Heidi Ledford, "Biohackers Gear up for Genome Editing," *Nature News*, August 26, 2015, https://www.nature.com/news/biohackers-gear-up-for-genome-editing-1.18236. Accessed January 3, 2020.
[23] Dana Carroll, "Genome Editing: Past, Present, and Future." *Yale Journal of Biological Medicine* 90, no. 4 (2019), 653 – 659. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5733845/

In the past, the only individuals capable of performing gene-editing projects were highly skilled biologists who worked in academia, industry, and government. This exclusivity of gene-editing research and development to these sectors is commonly attributed to difficult technical knowledge and capabilities requirements, along with the prohibitively large costs of running gene-editing protocols.

However, gene-editing well-characterized bacteria like baker's yeast and BSL-1 lab strains of *Escherichia coli* is slowly becoming a common practice in modern DIYBio settings. DIYBio community labs across the United States even held basic hands-on classes in using the revolutionary genome editing technique called the Clustered Regularly Interspaced Short Palindromic Repeat (CRISPR)-Cas9 system – a system that one of its creators, Dr. Jennifer Doudna, says is easier to use, cheaper to develop, and generates less unintended effects than previous generations of gene-editing technologies.[24] Many community labs and biohackers do innocuous experiments on well-characterized organisms like yeast cells as a part of their hands-on learning of the CRISPR technique.[25]

However, even limited access to CRISPR alone raises concerns that DIYBio community members will hack genomes for questionable purposes. There are members

[24] Molly Campbell, "Technology Networks Explores the CRISPR Revolution: An Interview With Professor Jennifer Doudna, Co-Developer of CRISPR Genome Editing Technology," *Technology Networks*, October 21, 2019, https://www.technologynetworks.com/genomics/articles/technoloy-networks-explores-the-crispr-revolution-an-interview-with-professor-jennifer-doudna-co-325876

[25] See Annie Sneed, "Mail-Order CRISPR Kits Allow Absolutely Anyone to Hack DNA," *Scientific American*, November 2, 2017, https://www.scientificamerican.com/article/mail-order-crispr-kits-allow-absolutely-anyone-to-hack-dna/; "Classes," *Genspace*, 2018, https://www.genspace.org/classes; "Build-A-Gene Course (Now More CRISPR)," *Baltimore Underground Science Space*, 2020, https://bugssonline.org/build-a-gene-now-more-crispr/; and "Hands-on CRISPR," *Global Community Bio Summit*, 2018, https://www.biosummit.org/handson-crispr.

of this diverse community that pull stunts that appear to validate these concerns. One such member is Dr. Josiah Zayner – a global leader in the biohacker movement with a diverse life sciences background in plant biology, cell and molecular biology, and biophysics. He is also the founder of a small biotech company called the ODIN, which specializes in selling reagents, equipment, and kits for citizen scientists and amateur biologists.[26]

Zayner has explicitly stated that his motivations are to constantly "push the boundaries of Science outside traditional environments."[27] These actions have garnered him much in the way of media attention and scrutiny. In 2015, he successfully crowdfunded over $70,000 for a DIY CRISPR kit project through the crowd-funding site IndieGoGo. He now sells these DIY CRISPR kits for $169 on his company website.[28] In 2016, he performed an unsanctioned fecal transplant on himself to relieve gastrointestinal distress.[29] In the same year, Zayner and the FDA had legal discussions over his production and sale of genetically modified yeast cells to produce glow-in-the-dark beer.[30] The following year at SynBioBeta, Zayner publicly injected himself with a

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[26] See "About Us," *The ODIN*, 2020, https://www.the-odin.com/about-us/; "Speakers for Biohack the Planet - 2020," *Biohack the Planet*, 2020, http://biohacktheplanet.com/2020-speakers/; and Molly Campbell, "Meet Josiah Zayner, the Biohacker Next Door," *Technology Networks*, June 21, 2019, https://www.technologynetworks.com/genomics/articles/meet-josiah-zayner-the-biohacker-next-door-320964. Accessed January 19, 2021.

[27] "About Us," *The ODIN*, 2020, https://www.the-odin.com/about-us/. Accessed January 3, 2021.

[28] Josiah Zayner, "DIY CRISPR Kits, Learn Modern Science By Doing," *Indiegogo*, November 4, 2015, https://www.indiegogo.com/projects/diy-crispr-kits-learn-modern-science-by-doing. Accessed January 19, 2021.

[29] Arielle Duhaime-Ross, "A Bitter Pill," *The Verge*, May 4, 2016, https://www.theverge.com/2016/5/4/11581994/fmt-fecal-matter-transplant-josiah-zayner-microbiome-ibs-c-diff. Accessed January 19, 2021.

[30] Sigal Samuel. "A Celebrity Biohacker Who Sells DIY Gene-Editing Kits is Under Investigation". *Vox*, May 19, 2019, https://www.vox.com/future-perfect/2019/5/19/18629771/biohacking-josiah-zayner-genetic-engineering-crispr. Accessed January 19, 2021.

CRISPR-based DNA construct that purportedly would increase his muscle growth capabilities.[31] While he expressed regret at his acts of self-experimentation, Zayner was back to self-injecting and live-broadcasting in 2020 – this time, it was a home-brewed, DNA-based alleged COVID-19 vaccine that he broadcast over Twitter.[32] These activities have raised suspicions of Zayner and, by proxy, other biohackers to the point that Zayner was investigated for practicing medicine without a license in the state of California in 2019.[33]

The alleged ubiquity, accessibility, and ease-of-use of life sciences knowledge, technology, and protocols are the foundation of an increasingly-utilized framework in national security circles – that advances in the life sciences are increasing the likelihood of biothreats from deliberate and accidental sources.[34] Biorisk experts and policymakers struggle with understanding how the risks of biological accidents and biological weapons change as the life sciences become increasingly accessible and affordable to a broader

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[31] Sarah Zhang. "A Biohacker Regrets Publicly Injecting Himself with CRISPR," *The Atlantic*, February 20, 2018, https://www.theatlantic.com/science/archive/2018/02/biohacking-stunts-crispr/553511/. Accessed January 19, 2021.

[32] Kristen V. Brown, "Home-Made Covid Vaccine Appeared to Work, but Questions Remained," *Bloomberg*, October 10, 2020, https://www.bloomberg.com/news/articles/2020-10-10/home-made-covid-vaccine-appeared-to-work-but-questions-remained. Accessed January 19, 2021.

[33] See Stephanie M. Lee, "DNA Biohackers Are Giving The FDA A Headache With Glow-In-The-Dark Booze," *BuzzFeed News*, December 6, 2016, https://www.buzzfeednews.com/article/stephaniemlee/biohacking-booze; Danielle Brooks and Jon Brooks, "After Ingesting Someone Else's Feces, Biohacker Feels Like New Man," *KQED*, May 11, 2017, https://www.kqed.org/futureofyou/384757/a-year-after-ingesting-someone-elses-feces-biohacker-feels-like-a-new-man; Sarah Zhang, "A Biohacker Regrets Publicly Injecting Himself With CRISPR," *The Atlantic*, February 21, 2018, https://www.theatlantic.com/science/archive/2018/02/biohacking-stunts-crispr/553511/; Beth Mole, "Genetic Self-Experimenting 'Biohacker' under Investigation by Health Officials," *Ars Technica*, May 16, 2019, https://arstechnica.com/science/2019/05/biohacker-who-tried-to-alter-his-dna-probed-for-illegally-practicing-medicine/; and Sigal Samuel, "A Celebrity Biohacker Who Sells DIY Gene-Editing Kits Is under Investigation," *Vox*, May 19, 2019, https://www.vox.com/future-perfect/2019/5/19/18629771/biohacking-josiah-zayner-genetic-engineering-crispr.

[34] Kathleen M Vogel, "Framing Biosecurity: an Alternative to the Biotech Revolution Model?," *Science and Public Policy* 35, no. 1 (January 2008): 45 - 54, https://doi.org/10.3152/030234208x270513.

range of actors.[35] Unfortunately, sensationalized news reports and media coverage on biohackers like Zayner only feed these concerns and do little to shed light on the relationship between the democratization of biology and their effects on the risks of biological accidents and bioweapons.

From a biosafety perspective, the majority of DIYBio members have little to no formal training in key life sciences areas like safety and ethics.[36] From a biosecurity perspective, easy access to research published online, cheaper and more capable equipment, and the trend towards the digitization of biology potentially opens the door to a future where individuals may be able to easily construct or modify genes or genomes from the comfort of their own home.[37] For the biorisk community, DIYBio represents a perfect storm of biological risk where the global diffusion of biology equipment, knowledge, and techniques are in the hands of individuals operating with lax or nonexistent biosafety and biosecurity oversight and regulations.

According to this national security framework, the DIYBio community presents significant biorisk threats to the United States. However, the DIYBio community has had no serious events or issues beyond some media-sensationalized actions taken by a few individuals like Josiah Zayner to date. It is also important to note that Josiah Zayner's

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[35] Gigi Kwik Gronvall. *Mitigating the Risks of Synthetic Biology*, Washington DC: Council on Foreign Relations, 2015, 3.
[36] Kolodziejczyk, Bart. "Do-It-Yourself Biology Shows Safety Risks to an Open Innovation Movement." *Brookings*, October 9, 2017, https://www.brookings.edu/blog/techtank/2017/10/09/do-it-yourself-biology-shows-safety-risks-of-an-open-innovation-movement/. Accessed 01/03/2020.
[37] Vogel (2008) "Framing Biosecurity": p. 46

actions resulted in either failure or a poor product despite even his PhD level expertise in the life sciences.[38]

Therefore, it is important to dig deeper into this issue and better understand the drives, design, and degree of democratization of these DIYBio community spaces. Better understanding the community by these metrics helps us answer the research question of this dissertation: does the DIYBio community change the biosafety and biosecurity threat landscape the way that the biorisk community predicts?

Separating Fact from Fiction - The Biorisk Community's Perspective

A significant challenge to understanding the potential biorisk threats associated with the DIYBio community is that little information exists about the inner workings of the community. A lack of communication between the DIYBio community, the media, and security analysts who evaluate potential threats also exacerbates this challenge. This misunderstanding of the DIYBio community has contributed to the rise of a security narrative based on three unfounded assumptions. The first holds that an increased access to life sciences technology necessarily implies an even distribution and use of the technology to all members of the community. The second puts the cart before the horse by assuming that the DIYBio community's motivations must be harmful as they represent

[38] See Beth Mole, "Genetic Self-Experimenting 'Biohacker' under Investigation by Health Officials," *Ars Technica*, May 16, 2019, https://arstechnica.com/science/2019/05/biohacker-who-tried-to-alter-his-dna-probed-for-illegally-practicing-medicine/; Arielle Duhaime-Ross, "A Bitter Pill," *The Verge*, May 4, 2016, https://www.theverge.com/2016/5/4/11581994/fmt-fecal-matter-transplant-josiah-zayner-microbiome-ibs-c-diff.; and Stephanie M. Lee, "DNA Biohackers Are Giving The FDA A Headache With Glow-In-The-Dark Booze," *BuzzFeed News,* December 6, 2016, https://www.buzzfeednews.com/article/stephaniemlee/biohacking-booze.

a significant biorisk to the world. Finally, the third assumption is that access to life science technologies is the only impediment to successful scientific research, development, and use.

History of the Biorisk Narrative

The seeds of suspicion were already sown concerning the garage biology and DIYBio community movements before they emerged in 2005 and 2008, respectively. In 2001, Dr. Steven Block, a biophysics professor at Stanford, argued that advancements in the life sciences made biological weapons use more likely; while he maintained that bioweapons threats from a garage lab scenario tended to be overexaggerated, he also did not dismiss such threats in the future.[39] Prior to the release of Carlson's garage biology article, the tech-sensationalizing publication *Wired* released an article in early 2005 on open source biology and how such platforms may make it easier to produce a biological weapon. Dr. Roger Brent, a molecular biology PhD and the lead of the Brent Lab at Fred Hutchison Cancer Research Center, even made the point to say that anyone could leverage open-source biology to "re-synthesize the SARS virus".[40]

Discourse and activity in response to the DIYBio movement following Carlson's 2005 article and the emergence of DIYBio in 2008 further confirms how suspect the community is viewed from the outside. In an interview for PBS News Hour, Peter Brent

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[39] Steven Block, "The Growing Threat of Biological Weapons," *American Scientist* 89, no. 1 (2001), 28. https://doi.org/10.1511/2001.1.28.
[40] David Cohn, "Open-Source Biology Evolves," *Wired,* January, 2005, https://www.wired.com/2005/01/open-source-biology-evolves/.

argued strongly for formal oversight measures of the activities of DIYBio scientists.[41] In 2009, the Federal Bureau of Investigation (FBI) began sending agents to DIYBio gatherings and conferences as people became concerned that hundreds of biohackers may create unknown pathogens in unmonitored garage labs.[42] These concerns were further echoed as distinct biosecurity, bioethical, and biosafety concerns of DIYBio scientists in a *Nature Biotechnology* commentary piece in 2009.[43] In 2010, the Presidential Commission for the Study of Bioethical Issues released a report stating that the DIY science community may create new risks as synthetic biology spreads to unconventional science spaces.[44]

Concerns of the DIYBio community increased in 2012 in the midst of the H5N1 gain-of-function experiments controversy, where experts weighed the benefits and risks of fully publishing the research of two separate teams of scientists who had successfully adapted the H5N1 avian influenza to allow mammal to mammal transmission.[45] With this backdrop, a 2012 New York Times article quoted renowned biosecurity experts and virologists to make the case that amateur scientists could create a mutated virus in light of

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[41] PBS News Hour with Jim Lehrer. "DIYBio on the News Hour." *YouTube* video, 10:00. December 2018. https://www.youtube.com/watch?v=-IIWH6Hhcnc

[42] Heidi Ledford, "Garage Biotech: Life Hackers," *Nature News*, October 6, 2010, https://www.nature.com/articles/467650a.

[43] Gaymon Bennett et al., "From Synthetic Biology to Biohacking: Are We Prepared?," *Nature Biotechnology* 27, no. 12 (2009), 1109 – 1111. https://doi.org/10.1038/nbt1209-1109.

[44] *New Directions: The Ethics of Synthetic Biology and Emerging Technologies*. Washington DC: Presidential Commission for the Study of Bioethical Issues, 2010.

[45] For examples, see Gregory D. Koblentz, "Dual-Use Research as a Wicked Problem," *Frontiers in Public Health* 2, no. 113 (2014), 113 – 116; Sonia Ben Ouagrham-Gormley and Shannon R. Fye, "Restricted Science," *Frontiers in Public Health* 2, no. 158 (2014), 1 – 3; and Gigi Kwik Gronvall, *H5N1: A Case Study for Dual-Use Research*, Washington DC: Council on Foreign Relations, 2013.

the H5N1 controversy.[46] The author quoted renowned biosecurity experts and virologists to make the case that amateur scientists were capable enough to do such things. In an atypical approach, Zimmer also presented quotes from the DIYBio community in his article that attempt to rebut this assertion, including one from DIYBio.org founder Jason Bobe who stated that "people overestimate our technological abilities and underestimate our ethics".[47]

This cycle of rising biorisk concern and DIYBio suspicions has a distinct pattern. As breakthroughs and discoveries happen in the life sciences, the biorisk community raises the point that these new breakthrough and discoveries may be misappropriated by a broader audience. This concern is exacerbated by the advent of tools and life sciences approaches that are meant to make biology easier to study and manipulate, including the easier-to-use gene-editing technique CRISPR-Cas9 and the engineering approach to biology known as synthetic biology. These approaches and tools then feed concerns that as the DIYBio community gains access and uses these techniques and approaches, biohackers may exploit these technologies in unsupervised and possibly unethical, illegal, or dangerous ways.[48]

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[46] In 2012, two separate studies successfully transformed a strain of a pathogenic avian influenza into mutant forms that could spread between mammals. As with past research concerning pathogen manipulation, great debate emerged in the scientific community about the validity of the need to run such experiments, as well as the potential risks associated with releasing the protocols, methods, and findings of these experiments to the global community.

[47] Zimmer, Carl. "Amateurs Are New Fear in Creating Mutant Virus," *New York Times*, March 5, 2012, https://www.nytimes.com/2012/03/06/health/amateur-biologists-are-new-fear-in-making-a-mutant-flu-virus.html?auth=login-email. Accessed January 5, 2020.

[48] For examples, see John Wikswo, Stephen Hummel, and Vito Quaranta, "The Biohacker: A Threat to National Security," *CTC Sentinel* 7, no. 1 (2014): 8 – 11; Nicholas Cropper, "CRISPR is Making Bioweapons More Accessible," *American Security Project*, April 29, 2020, https://www.americansecurityproject.org/crispr-is-making-bioweapons-more-accessible/. Accessed February 28, 2021; Rachel M. West and Gigi Kwik Gronvall, "CRISPR Cautions: Biosecurity Implications

The cycle continues to the modern day where DIYBio remains suspect in the eyes of the media and the biorisk community. A 2018 article in the New York Times titled "As D.I.Y. Gene Editing Gains Popularity, 'Someone is Going to Get Hurt'" built on the successful reconstruction of horsepox at the University of Alberta through mail-order DNA to present a narrative of a technological wild west in the life sciences: an emerging, unregulated community with copious amounts of self-experimentation and questionable science. Baumgaertner, the author of the New York Times article, quotes prominent figures in the scientific and biorisk communities to further the dominant narrative that this community is potentially a ticking time-bomb: the catalyst to either an accidental or deliberate biological disaster waiting to happen.[49] This article portrayed the DIYBio community as irresponsible at best, and a potential national security threat at worst.[50]

Biorisk Assumption #1 – Limitless Democratization versus Narrow Accessibility

Researchers and national security experts refer to the movement as a manifestation of life sciences democratization – life sciences activity happening in

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of Gene Editing," *Perspectives in Biology and Medicine* 63, no. 1 (2020), 73 – 92; and Margaret Talbot, "The Rogue Experimenters", *The New Yorker*, May 18, 2020, https://www.newyorker.com/magazine/2020/05/25/the-rogue-experimenters. Accessed February 28, 2020.

[49] Baumgaertner, Emily. "As D.I.Y. Gene Editing Gains Popularity, 'Someone is Going to Get Hurt'," *New York Times*, Mary 14, 2018, https://www.nytimes.com/2018/05/14/science/biohackers-gene-editing-virus.html. Accessed January 5, 2020.

[50] See Bart Kolodziejczyk, "Do-It-Yourself Biology Shows Safety Risks of an Open Innovation Movement," *Brookings*, October 6, 2017, https://www.brookings.edu/blog/techtank/2017/10/09/do-it-yourself-biology-shows-safety-risks-of-an-open-innovation-movement/; Carl Zimmer, "Amateurs Are New Fear in Creating Mutant Virus," *The New York Times*, March 5, 2012, https://www.nytimes.com/2012/03/06/health/amateur-biologists-are-new-fear-in-making-a-mutant-flu-virus.html?auth=login-email; and Gronvall, (2015) *Mitigating the Risks*.

unconventional spaces due to both the de-skilling and increased accessibility of materials, equipment, and information of biology. The national security expert narrative has very particular views on the idea of broadening science activities and participation to citizens and amateurs in unconventional spaces – the tangible and intangible elements that allow democratization is perceived to raise the likelihood of state and nonstate actor misuse of advanced biotechnologies. Vogel's discussion on the dominant biosecurity framework encapsulates the underpinnings of this predicted outcome succinctly. Part of this perception comes from the idea that threat is a numbers game - the more technologies and information are distributed to a broader pool of participants, the higher the likelihood that an accidental or deliberate harmful biological event will occur. The second is that a broader participant pool is inevitable and infinite, which raises concerns that there is no oversight mechanism sufficient to address the rising risk of biothreats – threats could come from anywhere, at any time, for any reason.[51]

This concern, particularly of nonstate actor misuse, has been strong in the biosecurity community given recent experiences such as the anthrax letter attacks of 2001 (Amerithrax), which left 5 dead and 17 injured through the dispersal of anthrax spores sent via letters through the U.S. post office system.[52] The primary suspect, microbiologist Dr. Bruce Ivins, was believed to have perpetrated the attacks as a way to draw attention and preserve funding for his work on anthrax vaccines at the U.S. Army Medical

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[51] Kathleen Vogel, "Framing Biosecurity: An Alternative to the Biotech Revolution Model?," *Science and Public Policy* 35, no. 1 (2008), 45 – 54.
[52] Gigi Kwik Gronvall, "Safety, Security, and Serving the Public Interest in Synthetic Biology," *Journal of Industrial Microbiology and Biotechnology* 45 (2018), 463 – 466.

Research Institute of Infectious Diseases (USAMRIID).[53] The idea that a single person, albeit with highly technical skills, knowledge, and access, could perpetrate a large-scale bioterrorist act on American soil raised concerns that Ivins' attack was only the harbinger of the tsunami of bioterrorism events to come. For the biorisk community, this tsunami of biorisk threats could only be rising as advances and trends in the life sciences make it easier and cheaper to conduct research and perform experiments, with experts extolling the risks of advances in genome editing, automation, and the inherent modularity of synthetic biology.[54]

This biorisk narrative not only focuses on active misuse of advanced biotechnologies. This narrative also argues that democratization raises the likelihood of incidents of small-scale accidents such as laboratory-acquired infections, as well as the inadvertent release of biological microbes in local communities and regions. This worry of accidents is based on a very real concern that amateurs performing biological experiments without traditional training may not have the correct practices, knowledge, and protocols to adequately maintain sterility and properly decontaminate make-shift lab spaces after use.[55]

However, this biorisk narrative makes the untenable assumption that democratization is a dichotomous phenomenon: a discipline and its component parts are either fully accessible to everyone or only accessible to a select few. This assumption is

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[53] "Amerithrax Investigative Summary and Errata," *Department of Justice*, February 19, 2010, https://www.justice.gov/archive/amerithrax/docs/amx-investigative-summary.pdf. Accessed February 28, 2021.
[54] Manfred S. Green, James LeDuc, Daniel Cohen, and David R. Franz, "Confronting the Threat of Bioterrorism: Realities, Challenges, and Defensive Strategies," *Lancet Infect Dis* 19 (2019), e2 – e 13.
[55] Ibid., 463 – 464.

foundational to what Dr. Kathleen Vogel discusses as the "biotech revolution model" of framing biosecurity risk. An example she uses to highlight this assumption is how this framework argues that the ubiquity of life sciences information, materials, gene synthesis companies, and equipment means *that almost anyone in the world* could construct the genomes for lethal pathogens.[56]

The biotechnology boom of the early 2000s did make access to equipment and tools for amateurs than in the past. The biotech boom and bust around 2008 contributed to a high turnover of biotech companies. This resulted in a large amount of second-hand equipment and tools finding their way to local and digital auction warehouses, where DIYBio enthusiasts and community labs cold purchase originally expensive equipment and tools at significant discounts.[57]

Further, DIYBio community members have a penchant for innovating new ways to either substitute or entirely replace necessary lab equipment and materials with their own inventions. Primers and guides on building your own DIYBio lab are easy to find online, and contain suggestions like heating test tubes in your armpits as a makeshift incubator, reversing the lens on a cheap webcam to use as a crude microscope, and 3-D printing an attachment for a Dremel rotary device to create an improvised centrifuge.[58] Community members have also created cheaper, more compact versions of equipment

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[56] Kathleen M. Vogel. "Framing Biosecurity: An Alternative to the Biotech Revolution Model?" *Science and Public Policy*, *35* (1), 2008, 45 – 54.
[57] Elliot Roth, "A Guide to DIYbio (Updated 2019)," *Medium*, July 14, 2019, https://medium.com/@ThatMrE/a-guide-to-diybio-updated-2019-abd0956cdf74. Accessed March 4, 2021.
[58] See Heidi Ledford, "Garage Biotech: Life Hackers," *Nature* 467 (2010): 650 – 652; Patrik D'haeseleer, "How to Set Up Your Own DIY Bio Lab," *Makezine,* https://makezine.com/2017/04/11/how-to-set-up-your-own-lab/. Accessed March 4, 2021; and Jonathan Cline, "DremelFuge DIY-Centrifuge Spins the Best!," *DIYBio*, March 21, 2010, https://diybio.org/2010/03/21/dremelfuge/. Accessed March 4, 2021.

such as open-source polymerase chain reaction (PCR) machines, centrifuges, and gel electrophoresis visualizers.[59]

In addition, more modern equipment is programmable and contains automatic features. These features contribute to a phenomenon known as de-skilling, where individuals require less knowledge and skills than in the to run specific protocols or experiments.

Finally, the internet facilitates the storage, transfer, and retrieval of scientific protocols for any individual with a computer and an internet connection.[60] DIYBio participants habitually research and share biology information independently and in an open-source fashion.[61] For access-restricted articles textbooks like those behind paywalls, online resources like Google Scholar, ResearchGate, LibGen, and Sci-Hub enable workarounds for the community.[62]

However, even as costs have plummeted for second-hand equipment and tools on local and digital auction platforms, there are still significant barriers for successful acquisition of using these equipment, materials, and information.[63] Equipment is by no means accessible to everyone: currently, a simple search on eBay for used polymerase-chain reaction (PCR) machines show that this equipment can cost anywhere between

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[59] See "OpenPCR," *OpenPCR*, https://openpcr.org/. Accessed March 4, 2021; "Mini16 Thermal Cycler," *MiniPCRBio*, https://www.minipcr.com/products/minipcr-mini16-thermal-cycler/. Accessed March 4, 2021; and "Bento Lab: Your Portable DNA Laboratory," *BentoBio*, https://www.bento.bio/product/bento-lab/. Accessed March 4, 2021.
[60] Jonathan Zittrain. "The Generative Internet." *Harvard Law Review* 119 (2006), 1975 – 2040.
[61] Stacey Kuznetsov, Carrie Doonan, Nathan Wilson, Swarna Mohan, Scott E. Hudson and Eric Paulos. "DIYBio *Things*: Open Source Biology Tools as Platforms for Hybrid Knowledge Production and Scientific Participations." In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2015, 4065- 4068.
[62] Roth. (2019). "A Guide to DIYBio."
[63] Landrain et al. (2013). "Do-It-Yourself Biology: Challenges.", 117.

$100 - $3300. Even equipment marketed to the community can be expensive: the portable lab known as Bento Lab combines a centrifuge, PCR machine, and a gel visualizer into a compact package for $1600.[64] These are still significant economic costs that present a major barrier to entry for casual hobbyists and amateurs.

In addition, the second-hand nature of the equipment also means adapting them to garage and unconventional settings that may prove to be difficult or impossible. For example, DIYBio members that wish to work with pathogens or sensitive tissues cultures would require specialized equipment, such as a laminar flow hood, to create a sterile workplace. However, laminar flow hoods tend to be large, expensive, and difficult to install, with typical costs ranging from $1,500 - $9,000 through a quick Google search.[65]

Having fully functional equipment is also an exceptionally large assumption to make when it comes to second-hand equipment. DIYBio members who purchase equipment on online auction forums like eBay are taking risks – they cannot inspect the equipment beforehand, are purchasing equipment that is out of warranty, and have little recourse if the equipment does not function properly. While there may be times when equipment can be fixed, this can be expensive.[66]

Further, physical barriers are not the only obstacles to performing complex scientific tasks. Works in science and technology literature show how tacit knowledge and expertise function as intangible barriers to the acquisition and use of specialized

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[64] Ibid.
[65] Richard Fuisz, "Caveat Creator," *Journal of Law and Biosciences* 4, no. 3 (2017), 658 – 670. https://doi.org/10.1093/jlblsx037.
[66] Derek Lowe, "In the Pipeline," *AAAS*, October 7, 2010, https://blogs.sciencemag.org/pipeline/archives/2010/10/07/more_on_garage_biotech. Accessed March 13, 2021.

skills and knowledge. Expertise is a deep knowledge of a subject area acquired through many years of study, practice, and experience.[67] Some of this knowledge is defined as explicit – knowledge that individuals in a subject area can communicate through verbal, pictorial, or written forms. However, a significant portion of this expertise is considered tacit knowledge – knowledge and skills that cannot be articulated, may not be consciously recognized or executed by the user, and are difficult to transfer between individuals.[68]

The difficulty in communicating, recognizing, and transferring tacit knowledge across individuals and geographies have significant impacts on science outcomes. First, specialized skills typically require long hours of practice to get the feel and innate understanding of the procedure. Second, the unconscious or unrecognized nature of tacit knowledge obfuscate factors that may be critical to an experiment's success, which makes replicating complex studies and practices difficult in different environmental settings. Third, the time-consuming nature of tacit knowledge transfer necessitates a trial-and-error approach to learning, which requires the instructor and the novice to invest significant time and resources commitments.[69]

In the DIYBio context, amateurs in the community lack the deep expertise and tacit knowledge of experts in the life sciences. This lack of expertise and tacit knowledge

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[67] See Sonia Ben Ouagrham-Gormley and Shannon R. Fye, "Restricted Science," *Frontiers in Public Health* 2, No. 158 (2014), 1 – 3. https://doi.org/10.3389/fpubh.2014.00158; Sonia Ben Ouagrham-Gormley, *Barriers to Bioweapons: The Challenge of Expertise and Organization for Weapons Development*, Ithaca, New York: Cornell University Press, 2014, 17 – 21; Kathleen Vogel, *Phantom Menace or Looming Danger?*, Baltimore, Maryland: Johns Hopkins Press, 2013, Loc 278 of 8781; and Harry Collins and Robert Evans, *Rethinking Expertise,* Chicago, Illinois: The University of Chicago Press, 2009, 24 – 27.
[68] Ben Ouagrham-Gormley, *Barriers to Bioweapons*, 18 – 26.
[69] Ibid., 18 – 26.

would present a significant barrier to the successful use of equipment and knowledge for DIYBio projects. Using the laminar flow hood example again, these hoods maintain sterility through a complex system of HEPA-filtered airflow. Part of this airflow effectively acts as a wall between the environment outside of the hood and the workspace within the hood, while another portion of the airflow continually directs air within the hood to a HEPA-filtered duct at the top of the hood.[70]

While the hood is a tool that helps maintain sterility, it is a difficult apparatus for amateurs to work with. There are many ways that untrained individuals may unintentionally contaminate their sterile workspace, including improperly washing their hands and arms before use, placing large objects near the back of the cabinet, using materials that were not properly disinfected, or even moving their arms too quickly during their experiment.[71] The inability to maintain sterility despite access to proper equipment highlights how a lack of expertise and tacit knowledge may have severe, detrimental impacts to the results of the experiments.[72]

Further, even in terms of explicit knowledge, amateurs unfamiliar with the life sciences would lack the expertise necessary to understand the basics of biological concepts, terminology, and other specialized knowledge. While resources like documents and textbooks are available online or can be purchased, this takes significant time and

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70 "Horizontal vs. Vertical Laminar Flow Hoods," *Lab Supply Network*, https://www.laboratory-supply.net/blog/horizontal-vs-vertical-laminar-flow-hoods/. Accessed March 04, 2021.
71 "Do's and Don'ts When Using Laminar Flow Cabinets," *ESCO*, October 13, 2015, http://www.escoglobal.com/news/do-s-and-don%E2%80%99ts-when-using-laminar-flow-cabinets/1218/. Accessed 03/06/2021.
72 Stacey Kuznetsov, Alex S. Taylor, Tim Regan, Nicolas Villar, and Eric Paulos, "At the Seams: DIYbio and Opportunities for HCI," in *Proceedings of the Designing Interactive Systems Conference*, June 12 – 15, 2012, 258 – 267.

dedication, to increase proficiency and gain expertise.[73] In addition, amateurs will have to figure out how to both filter out questionable information in their searches and avoid engaging in unsafe practices. While there are fora online ranging from the overarching DIYBio.org to individual community lab websites that present curated information, other community platforms are not meticulously curated, edited, or fact-checked. These community platforms may contain questionable practices, topics, and protocols for injecting nerve growth factor to increase an individual' sense of smell, creating radiation resistant blood, and finding ways to alter the human body to accommodate housing hive insects.[74]

Finally, the conversation in the United States and Global North nations often take the existence and use of the internet as a given. Despite assumptions about its wide accessibility, significant populations domestically and globally lack access to the internet. Approximately 10% of the United States lacks any internet connection, and only 73% of Americans have access to broadband at home. Access also varies across racial and socioeconomic strata, where Caucasians and the rich have more connectivity, while communities of color or poverty have less. Globally, the numbers are even lower – little more than half the world's population has internet access, and capabilities vary wildly across Global North and Global South nations.[75] The variance in both access and quality of service across Global North and South implies that the democratization of

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[73] K.A. Ericsson and Jacqui Smith, *Towards a General Theory of Expertise: Prospects and Limits*, Cambridge, UK: Cambridge University Press, 1991, 302.
[74] Richard Fuisz. "Caveat Creator." *Journal of Law and Biosciences* 4, no. 3, 2017, 658 – 670.
[75] International Telecommunication Union, *Measuring Digital Development - Facts and Figures*. Geneva, Switzerland, 2019.

biotechnology and the rise of the DIYBio movement is largely restricted to those areas with sufficient wealth and internet capability.

Resolving Biorisk Assumption #1 – DIYBio and its Degree of Democratization

Therefore, one factor that needs to be explored is the degree to democratization of the life sciences. In the academic, biorisk, and DIYBio literatures, democratization is the result of varying degrees of access – as something becomes more democratized, it is easier to access, and vice versa.[76] In the context of DIYBio community labs, democratization refers to increasing access to a broader audience that can now participate in the life sciences – those that exist outside of traditional institutions like academia, industry, and government.[77]

This concept of access overlaps significantly with Harvard internet law professor and expert Jonathan Zittrain's concept of "generativity" – the degree to which a technology facilitates the individual use and communal distribution of a technology and

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[76] For examples, see Pippa Norris, *Digital Divide: Civic Engagement, Information Poverty, and the Internet Worldwide,* Cambridge, UK: Cambridge University Press, 2001; Deborah L. Wheeler, "Empowering Publics: Information Technology and Democratization in the Arab World – Lessons from Internet Cafes and Beyond," *Oxford Internet Institute* 11 (2006), 1 – 18; J.B. Holbrook, "Open Science, Open Access, and the Democratization of Knowledge," *Issues in Science and Technology* 35, no. 3, 2019, 26 – 28; Jeremy Hunsinger and Andrew Schrock, "The Democratization of Hacking and Making," *New Media and Society* 18, no.4, 2016, 535 – 538; Harrison W. Inefuku, "Globalization, Open Access, and the Democratization of Knowledge," *Educause Review* 54, no. 4, 2017, 62 – 63; and Jonathan Zittrain, "The Generative Internet," *Harvard Law Review* 1974, 2006: 1975 – 2040.

[77] For examples, see Morgan Meyer, "Domesticating and Democratizing Science: A Geography of Do-It-Yourself Biology," Working Paper 13-MS-04 for the Interdisciplinary Institute for Innovation, 2013: 1 – 22; Jozef Keulartz and Henk van den Belt, "DIY-Bio – Economic, Epistemological, and Ethical Implications and Ambivalences," *Life Sciences, Society, and Policy* 12, no. 7, 2016, https://doi.org/10.1186/s40504-016-0039-1; Barba, "We Are Biohackers," 2 – 26; Seyfried et al., "European Do-It-Yourself (DIY) Biology,": 548 – 551; and Gigi Kwik Gronvall, "Synthetic Biology: Biosecurity and Biosafety Implications," in *Defense Against Biological Attacks*, edited by S. Singh and Jens Kuhn. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-03053-7_11.

its applications.[78] Zittrain uses several examples to explain the four elements that determine the overall generativity of a tool, such as paper, saws, plowshares, pencils, airplanes, the personal computer, and the internet. Zittrain views highly generative technologies as those that increase the ability of users (capacity for leverage) to generate new, valuable uses (ease of mastery and adaptability) that are easy to distribute (accessibility) and are, in turn, sources of further innovation (adaptability).

When placed under the scrutiny of Zittrain's generative technology model, the DIYBio movement can potentially be considered a form of a highly-generative, techno-social phenomenon. First, capacity for leveraging biotechnology is becoming easier in some dimensions due to the "de-skilling" in existing life sciences technologies. This de-skilling is limited by intangible barriers such as tacit knowledge and expertise barriers that amateurs would have to overcome.[79] However, there are developments in the DIYBio community that can be seen as de-skilling, such as pre-packaged kits from the

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[78] Zittrain, "The Generative Internet,": 1978 – 1982.

[79] With amateur participants, it will be difficult to overcome the need for expert advice and the close oversight and trust necessary to effectively build, transfer, and use tacit knowledge – knowledge that is housed within a person, difficult to verbalize, not necessarily consciously-implemented, and is often fixed to a specific temporal and geographic context. For examples, see Vogel, *Phantom Menace or Looming Danger*, Loc 1291 – 1986; Iris Hunger, Jez Littlewood, Caitriona McLeish, Piers Millett, and Ralf Trapp, "Roundtable: The Future of Biothreat Governance," in *Biological Threats in the 21st Century*, London, UK: Imperial College Press, 2016, 431 – 450; Ben Ouagrham-Gormley, *Barriers to Bioweapons*, 2014, 17 – 63; and Sonia Ben Ouagrham-Gormley and Kathleen M. Vogel, "The Social Context Shaping Bioweapons (Non)proliferation," *Biosecurity and Bioterrorism* 8, no. 1 (2010), 9 – 24; Sonia Ben Ouagrham-Gormley and Shannon R. Fye-Marnien. "Is CRISPR a security threat?". In *Defense Against Biological Attacks*, 233 - 251. Springer, Cham, 2019; Kathleen M. Vogel and Sonia Ben Ouagrham-Gormley, "Anticipating Emerging Biotechnology Threats: A Case Study of CRISPR," *Politics and the Life Sciences* 37, no. 2, 203 – 219; and Kendall Hoyt, *Long Shot: Vaccines for National Defense*, Cambridge, MA: Harvard University Press, 2012: Loc 529 – 858.

[79] See Hoyt, *Long Shot*, Loc 71 – 87; Ben Ouagrham-Gormley, *Barriers to Bioweapons,* 2014, 17 – 24; and Vogel, *Phantom Menace or Looming Danger*, Loc 1925.

ODIN to do limited gene-editing experiments, as well as the open-source automated pipetting machine developed in Genspace called OpenTrons.[80]

Second, the DIYBio community has shown a remarkable capability for repurposing existing technologies or creating low-cost alternatives for lab equipment. Articles and primers on the internet share how reversing the lens in a webcam can be used to create small microscopes, using the heat from one's own armpits can work as a makeshift incubator, and printing open-source parts and attaching them to a Dremel rotary tool can function as a makeshift centrifuge.[81]

Third, the emergence and rise of the DIYBio community implies that the life sciences are easy to master and implement. This perceived ease of mastery dovetails in the DIYBio context with two considerations. The first is that the life sciences are being researched and practice by amateurs outside of academic institutions. The second is how the emergence of DIYBio temporally and narratively corresponds with the rise of synthetic biology – an engineering approach to the life sciences. The goal of both movements is to make biology more accessible and easier to perform than ever.[82]

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[80] For examples, see "DIY Bacterial Gene Engineering CRISPR Kit," *The ODIN*, https://www.the-odin.com/diy-crispr-kit/. Accessed March 14, 2021; "Bacterial CRISPR and Fluorescent Yeast Combo Kit," *The ODIN*, https://www.the-odin.com/bacterial-crispr-and-fluorescent-yeast-combo-kit/. Accessed March 14, 2021; "Meet the OT-2: Lab Automation has Never Been Easier," *OpenTrons*, https://opentrons.com/ot-2. Accessed March 14, 2021; and "New High-Precision Pipettes: Reliable Liquid Transfers from 1 – 1000 microliters," *OpenTrons*, https://opentrons.com/pipettes. Accessed March 14, 2021.

[81] For examples, see Ledford, "Garage Biotech" and D'Haeseleer, "How to Set Up Your Own DIY Bio Lab".

[82] For examples, see Sophia Roosth, *Synthetic: How Life Got Made,* Chicago, IL: University of Chicago Press, 2017, 127 – 144; Landrain et al., "Do-It-Yourself Biology,": 115 – 118; Gigi Kwik Gronvall, "Safety, Security, and Serving the Public Interest in Synthetic Biology," *Journal of Industrial Microbiology and Biotechnology* 45, 2018, 463 – 466; and Roth, "A Guide to DIYbio,".

Fourth, the DIYBio movement would not be possible without recent developments which enable increased accessibility to tools, information, and materials. The generative nature of the internet, combined with diminishing costs in life sciences equipment, allow DIYBio members to gain access to tools, numerous resources of information, leveraging online platforms for financial crowdfunding, and practitioners both online and in-person willing to share their knowledge, experiences, and lessons-learned in doing personal and group projects in this context.

What is problematic about Zittrain's generativity model is that the assessments he used were not consistent. Rather, much of the assessment of the generativity of a technology or its derived tool is based on relative assessments – how the tools or technologies he chose to highlight compare with other referenced tools and technologies. Zittrain describes how paper may be considered more generative than a plowshare or a sword due to how paper has many potential uses in other situations, as opposed to plowshares that are predominantly restricted to use for planting and swords are restricted typically to use for battle. In addition, he then describes how paper is accessible and individuals can use it for a multitude of purposes, how it is easy to master, and how adaptable it is without considering the context in which a product or technology might be used – for example, a person might appreciate a sword in a battlefield as opposed to fighting in battle with a sheet of paper.[83]

Despite the flaws in Zittrain's model, his concept of generativity serves to highlight the importance of accessibility for both generativity and democratization. This

[83] Zittrain, "The Generative Internet,", 1981 – 1982.

dissertation takes advantage of this overlap and uses 2 components of accessibility to measure the degree of democratization in the case of DIYBio: the degree to which DIYBio represents a fully democratized outcome of life sciences technology. The first facet of accessibility considered in this dissertation is market accessibility – the degree to which a drive exists to increase the accessibility of equipment, materials, tools, reagents, and other goods associated with the life sciences by decreasing the costs associated with accessing such items outside of academia, industry, and government. The second facet of accessibility considered in this dissertation is information accessibility – the degree to which a drive exists to make information obtainable and collaboration possible across individuals and communities that fall outside traditional life sciences institutions like academia, industry, and government.

Biorisk Assumption #2 – Malicious vs. Transformative Drives

The ease of overcoming technical barriers and increased access to equipment, information, and materials to the life sciences are not the only thing that raise red flags for the biorisk community. The biorisk community also takes the impressions, rhetoric, and actions of the community seriously to ascertain its intentions and motivations.

This practice of ascertaining an individual or a group's intentions and motivations is common practice in U.S. threat assessments.[84] The reason for expanding a threat assessment beyond a capabilities-based approach is to gain a more accurate, holistic measure of whether a group may seek to research, acquire, and use biological weapons.

[84] Vogel, *Phantom Menace*, Loc 1276.

Therefore, if a group has the capabilities, but not the motivation, to acquire and use a biological weapon, the biorisk community may be less concerned about the possibility of a bioterrorism attack.[85]

It is important to note that the concern of bioterrorism was very much on the minds of the biorisk community during the emergence of DIYBio in the United States. Several chem/bio terrorist events, such as the 1984 Rajneeshee bioterror attack, the 1995 Tokyo subway sarin attacks conducted by the cult Aum Shinrikyo, and the 2001 Amerithrax letters attack, seemed to indicate that CBW acts of terrorism were on the rise.[86] Al'Qaeda, a non-state adversary whose best-known achievement is the successful execution of the 9/11 attacks, had also expressed great interest in obtaining and using biological weapons against the United States.[87] This threat only seemed to grow as knowledge and capabilities became more easily distributed, accessible, and used.[88]

Within this context, this dissertation highlights how two phenomena converged to incentivize the biorisk community to either assume or presume that the DIYBio community had potentially malicious motivations. The first of these is what this dissertation calls the "garage biology narrative" – a narrative that supposed an unknown number of garage biohackers could be operating in the shadows to create and release pathogens against their local communities, states, and even the nation. The roots of this

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[85] Jonathan B. Tucker, "Introduction," In *Toxic Terror*, 2000: 6 – 12.
[86] Richard Danzig, "A Policymaker's Guide to Bioterrorism and What to Do About It," Washington, DC: National Defense University Press, 2009, 13.
[87] Rolf Mowatt-Larssen, "Al Qaeda Weapons of Mass Destruction Threat: Hype or Reality?," *Belfer Center for Science and International Affairs*, January, 2010, https://www.belfercenter.org/publication/al-qaeda-weapons-mass-destruction-threat-hype-or-reality. Accessed March 8, 2021.
[88] See Vogel, "Reframing Biosecurity," 45 and Judith Reppy, "Regulating Biotechnology in the Age of Homeland Security," *Science and Technology Studies* 16, no. 2, 2003: 38 – 51.

narrative can be traced to the biorisk concern that biohackers can access technologies, materials, equipment, and information with no oversight mechanism to track the purchases, review projects, and determine outputs from the community. The lack of an oversight mechanism is of particular concern to the law enforcement community, since it would be extremely difficult to detect, intervene, mitigate, or hold accountable any biohacker that ended up using these capabilities for nefarious purposes.[89] Therefore, from a biorisk perspective, it is less risky to treat unknown entities as potential threats than to be proven wrong and experience a bioterrorism incident.[90]

In addition, DIYBio values and rhetoric can come off as very disruptive, and potentially destructive, to outside observers. These disruptive components in DIYBio values and rhetoric can be seen in two ways. First, the language that the community uses to express its intentions and goals incorporate elements of rebellion against the status quo.[91] Members have generated manifestos and other political communications that use disruptive terms and phrases such as "let's pull these technologies out of the ivory

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[89] See Gaymon Bennett, Nils Gilman, Anthony Stavrianakis, and Paul Rabinow, "From Synthetic Biology to Biohacking: Are We Prepared?," *Nature Biotechnology* 27, no. 12, 2009, 1109 – 1111; "Garage Biology," *Nature* 467, 2010, 634; Markus Schmidt, "Diffusion of Synthetic Biology: A Challenge to Biosafety," *Systems and Synthetic Biology* 2, 2008, 1 – 6; "Garage-Lab Bugs: Spread of Bioscience Increases Bioterrorism Risks," *Homeland Security News Wire*, August 13, 2010, http://www.homelandsecuritynewswire.com/garage-lab-bugs-spread-bioscience-increases-bioterrorism-risks?page=0,0. Accessed March 7, 2021; Keith Johnson, "Gains in Bioscience Cause Terror Fears," *The Wall Street Journal,* August 11, 2010, https://www.wsj.com/articles/SB10001424052748703722804575369394068436132. Accessed March 7, 2021; and Presidential Commission, *New Directions: The Ethics of Synthetic Biology,* 2010, 8 – 13.

[90] This view is commonly associated with then-US Vice President Dick Cheney's proclamation that "even if there's just a one percent chance of the unimaginable come due, act as if it is a certainty." This statement is considered the foundation for what is referred to as the "One Percent Doctrine" - if a possibility exists, act as if the possibility would become reality. Further details on this doctrine and its application are available in Ron Suskind, *The One Percent Doctrine: Deep Inside America's Pursuit of its Enemies Since 9/11*, New York, NY: Simon & Schuester, 2006.

[91] Alessandro Delfanti, "Hacking Genomes. The Ethics of Open and Rebel Biology," *International Review of Information Ethics* 15, 2011, 53 – 57.

tower", "armed with curiosity and the scientific method", "for far too long, science has been locked away in 'ivory towers' of universities and research labs', and how the community "deplores restrictions on independent research, for the right to arrive independently at an understanding of the world around oneself is a fundamental human right".[92] One of the most prominent DIYBio community labs in the United States speaks to this phenomenon by its very name: Counter Culture Labs.[93]

Second, a fundamental goal of DIYBio is to make biotechnology accessible to *everyone*.[94] This goal runs counter to the status quo where science is conducted by highly-trained experts in traditional spaces like academia, industry, and government. Further, as seen through Vogel's biotech revolution model, this runs counter to what the biorisk community would desire in terms of access to technology, materials, equipment, and knowledge.[95] Letting any untrained amateur have access to the tools and knowledge to conduct their own biological experiments with no oversight is the biorisk community's worst nightmare.

Despite the rebellious language and disruptive goals of DIYBio, there are three reasons why it is a bridge too far to state that the DIYBio community has intentions and motivations to use life sciences tools, materials, and knowledge for malevolent purposes.

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[92] See Michelle L. McGowan, Suparna Choudhury, Eric T. Juengst, et al., "'Let's Pull These Technologies Out of the Ivory Tower': The Politics, Ethos, and Ironies of Participant-Driven Genomic Research," *BioSocieties* 12, 2017, 494 – 519; "About Us: Info and History," *Counter Culture Labs*, https://www.counterculturelabs.org/info--history.html. Accessed March 8, 2021; and Meredith L. Patterson, "A Biopunk Manifesto," *LiveJournal*, January 30, 2010, https://maradydd.livejournal.com/496085.html. Accessed March 8, 2021.

[93] Ibid.

[94] Ellen Jorgensen, "TED Talk: Biohacking – You Can Do It, Too," *TED Talk*, June, 2012, https://www.ted.com/talks/ellen_jorgensen_biohacking_you_can_do_it_too/up-next?language=en. Accessed March 8, 2021.

[95] Vogel, "Framing Biosecurity", 46 - 48.

While the DIYBio community does have ideological objectives such as democratizing technology and seizing scientific practices from the hands of the elite, the methods that the community has chosen to use to fulfill these goals are peaceful and lawful in nature. These acts include setting up community labs where people pool resources to do projects in spaces that meet local health and safety requirements, collaborating online together to work on complex group projects, and holding seminars with invited experts to educate members and the public on contemporary scientific and social topics. This type of non-violent and constructive engagement runs contrary to what the biorisk community should expect if the DIYBio community represented a bioterrorism risk.[96]

Second, despite its de-centralized nature that seeks to empower their members to pursue their own research interests and desires, the DIYBio community does self-govern its membership. One way it does this is to have members adhere to a Code of Ethics developed in 2011, which prioritizes values such as adopting safe practices, using biotechnology only for peaceful purposes, respecting humans and all living systems, and being accountable for upholding the code and their own actions.[97] For those that operate in a community space and violate procedures repeatedly, peer policing and reporting procedures are oversight mechanisms that community labs leverage to halt risky or

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[96] In his foundational work on studying bioterrorism and biocrimes, Dr. W. Seth Carus notes that bioterrorism involves "the threat or use of biological agents by individuals or groups motivated" by some sort of objective. These objectives may be personal, religious, political, ecological, or some other ideological driver. A key element in Carus' conceptualization of bioterrorism here is the desire to use biological weapons as a vehicle to coerce or execute change that matches their ideology through violence. The lack of this desire to use violence to execute ideological change should be noteworthy to the biorisk community concerning DIYBio motivations and intentions. For more, see W. Seth Carus, "Bioterrorism and Biocrimes: Illicit Use of Biological Agents Since 1900," Washington DC: National Defense University Press, 2001.

[97] "Draft DIYbio Code of Ethics from European Congress – 2011," *DIYBio*, 2011, https://diybio.org/codes/draft-diybio-code-of-ethics-from-european-congress/. Accessed March 8, 2021.

unacceptable behavior.[98] In some cases, after repeated warnings concerning said behavior, members have been known to be banned from community lab spaces.[99]

Finally, there is evidence that the community strives to do the right thing about addressing potential biorisk threats. Following concerns about the emergence of the community in 2009, the Federal Bureau of Investigation (FBI) began to conduct outreach to key members of the DIYBio community through a series of conferences and meetings. Over time, the FBI and the DIYBio community have built a partnership of mutual benefit – the FBI has direct contact with DIYBio members and used the relationship to emphasize the importance and practice of addressing biorisk threats, and the DIYBio community can invoke FBI connections and oversight to dismiss sensationalism and negative press.[100] Further, the DIYBio community held its inaugural class on biosafety basics, concepts, protocols, practices, and administrative considerations in August 2019 using funds from the research and grantmaking foundation Open Philanthropy. This three-day event brought together biohackers and community lab members from across the globe, as well as professional instructors from the American Biological Safety Association (ABSA). Topics ranged from discussing individual and shared experiences to

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[98] Gerstein, "DIY Bio: Separating Fact from Fiction".
[99] See "Board Call for Extraordinary General – Labitat," *Labitat*, November 26, 2014, http://lists.labitat.dk/pipermail/members/2014-November/001119.html. Accessed March 8, 2021; and "Banned – Individuals Asked to Leave or Banned From the Omni Physical Space," *Omni Commons Wiki*, https://omnicommons.org/wiki/Banned. Accessed March 8, 2021.
[100] Sara Tocchetti and Sara Angeli Aguiton, "Is an FBI Agent a DIY Biologist List Any Other? A Cultural Analysis of a Biosecurity Risk," *Science, Technology, and Human Values* 40, no. 5, 2015, 825 – 853.

risk assessments and biosafety, which enabled community labs and independent biohackers to consider, improve, and develop their own biosafety practices.[101]

Resolving Biorisk Assumption #2 – The Drives of DIYBio Founders and Members

Therefore, a second factor that needs to be explored are the drives of DIYBio founders and members, where drives refer to the motivations of the community. As mentioned in the Biorisk Assumption #2 section, the bioterrorism literature indicates that motivations play a critical role in whether non-state actors choose to pursue bioterrorism.[102]

The literature highlights potential motivations that are associated with non-state actors and choosing to pursue biological weapons. According to WMD terrorism expert Jonathan Tucker, motivations can include religious, nationalist, and ecological motivations that drive terrorists to use any means to destroy their adversaries.[103] WMD terrorism expert Seth Carus expands further in his work on biocrimes and bioterrorism by noting that non-state actors that engage in bioterrorism use such weapons on behalf of a "political, religious, ecological, or other ideological cause".[104]

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[101] See "Checking Ourselves before Wrecking Ourselves: Co-Evolving Innovation and Safety in the DIYBio Community," *BUGSS,* https://bugssonline.org/community/diybio-biosafety/. Accessed March 8, 2021; "Upgrading Biosafety and Biosecurity: Open Philanthropy Awards $700k for DIYbio," *SynBioBeta*, https://synbiobeta.com/upgrading-biosafety-biosecurity-open-philanthropy-awards-700k-diybio/. Accessed March 8, 2021; and David Gillum, "Building a Biosafety and Biosecurity Relationship with the iGEM and DIY Communities," *ABSA International*, https://absa.org/building-a-biosafety-and-biosecurity-relationship-with-the-igem-and-diy-communities/. Accessed March 8, 2021.
[102] Tucker, *Toxic Terror*: 9 – 12.
[103] Ibid., 11.
[104] Carus, "Bioterrorism and Biocrimes,": 3 – 4.

Therefore, understanding two drivers is essential in determining whether a non-state actor displays the malicious motivation to pursue biological weapons. The first is an ideological component – some desired outcome based on political, religious, ecological, or other ideological cause. The existing literature on DIYBio provides clear evidence that the movement has a socio-political ideology that guides it – an ideology based on generating social, economic, and political change to democratize science and all anyone to do science in their own time, in their own space, and on their own terms.[105]

The second driver to study is a propensity for destruction or violence. The potential risks of democratized technologies and the lack of communication between the DIYBio and biorisk communities make this driver a key element to study to help determine how the drivers of the DIYBio community change the likelihood of biorisk events happening in the United States.[106]

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[105] For examples, see Keulartz and van den Belt, "DIY-Bio – Economic, Epistemological,", 5; Ikemoto, "DIY Bio: Hacking Life,", 548; "Biohacking: Democratization of Science or Just a Quirky Hobby?," *LaBiotech.eu*, https://www.labiotech.eu/in-depth/biohacking-democratisation-science-hobby/. Accessed March 14, 2021; Meyer, "Domesticating and Democratizing Science,", 2 – 14; Landrain et al., "Do-It-Yourself Biology: Challenges and Promises,", 115 – 122; Seyfried et al., "European Do-It-Yourself (DIY) Biology,", 548 – 549; Ishaan Dev, "Democratizing Synthetic Biology: Balancing Biosecurity, Biosafety, and Citizen Science," *Washington Internships for Students of Engineering*, https://wise-intern.org/wp-content/uploads/2019/04/WISE_AIChE-Final-Draft_Ishaan-Dev.pdf. Accessed March 14, 2021; and Margaret Talbot, "The Rogue Experimenters," *The New Yorker*, https://www.newyorker.com/magazine/2020/05/25/the-rogue-experimenters. Accessed March 14, 2021.

[106] For examples, see Jonathan B. Tucker, "Introduction," In *Toxic Terror*, 2000, 6 – 12; Richard Danzig, "A Policymaker's Guide to Bioterrorism and What to Do About It," Washington, DC: National Defense University Press, 2009, 13; and W. Seth Carus, "Bioterrorism and Biocrimes: Illicit Use of Biological Agents Since 1900," Washington DC: National Defense University Press, 2001.

Biorisk Assumption #3 – Limitless Scientific Accomplishments vs. Tacit Knowledge, Organizational, Managerial, Social, and Resource Design Limitations

Finally, the biorisk narrative assumes that with the right equipment, materials, and information, complex scientific tasks and projects can be done anywhere, at any time, and in any situation. In turn, the biorisk community fears the ubiquity of complex scientific tasks and projects since the implications are potentially devastating – anyone, from anywhere, at any time, may be using easily accessible and deskilled technical capabilities and information to research, develop, weaponize, and deploy biological agents. Again, this assumption perfectly aligns with Vogel's work on the biotech revolution model – the dominant model that the biorisk community uses to frame its understanding of emerging biological threats.[107]

This focus on the ubiquity and ease of scientific achievements is rooted in the perception that scientists were accomplishing historically complex scientific tasks and experiments with relative ease compared to past genetics-related endeavors through rapid technological advances. In the biorisk community, one reason given for this increase in accomplishing complex endeavors was advancements in biotech. For example, one such technology was synthetic genomics – a development at the intersection of biology and chemistry that allowed scientists to chemically-create and DNA molecules for research and application purposes.[108] This technology was fundamental for the success of cutting-edge, novel biology experiments such as the J. Craig Venter Institute's successful

[107] Vogel, "Reframing Biosecurity", 45 – 48.
[108] Michael G. Montague, Carole Lartigue, and Sanjay Vashee, "Synthetic Genomics: Potential and Limitations," *Current Opinion in Biotechnology* 23, no. 5, 2012, 659 – 665.

creation of the world's first synthetic self-replicating chromosome and Eckard Wimmer's chemical synthesis of the polio genome through mail-order DNA.[109]

Untethering DNA molecule design and creation from the natural world to one which only requires a computer, the right software, and a synthesizer did more than unlock new capabilities for scientists and a global industry of custom DNA-synthesis companies. It also opened a discussion on how synthetic genomics had beneficial and harmful applications – an issue in the biorisk community referred to as the dual-use dilemma. Of particular concern was how the convergence of synthetic genomics with online availability of DNA sequences would make it significantly easier for malicious actors, potentially including biohackers, to artificially create and gain access to dangerous viral pathogens.[110]

The supposed capability for anyone to accomplish complex scientific tasks and projects in any locale makes it no surprise that the biorisk community would be concerned with the DIYBio community. Biorisk experts emphasize how the community has grown globally, how many more community labs now exist, and how these spaces now leverage advanced biotech like gene-editing for their classes and experiments.[111] If

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[109] Andrew Hessel, Marc Goodman, and Steven Kotler, "Hacking the President's DNA," *The Atlantic*, November, 2012, https://www.theatlantic.com/magazine/archive/2012/11/hacking-the-presidents-dna/309147/. Accessed March 10, 2021.
[110] Filippa Lentzos and Pamela Silver, "Chapter 8: Synthesis of Viral Genomes," in *Innovation, Dual Use, and Security: Managing the Risks of Emerging Biological and Chemical Technologies*, ed. Jonathan B. Tucker, Cambridge, MA: MIT Press, 2012, 133 – 145.
[111] See Sonia Ben Ouagrham-Gormley and Shannon R. Fye-Marnien. "Is CRISPR a Security Threat?". In *Defense Against Biological Attacks*, 233 - 251. Springer, Cham, 2019; Stew Magnuson. "Growing Public Interest in Genetic Science Sparks Some Bio-Security Concerns." *National Defense* 679, 2010, 44; Dustin Holloway. "Regulating Amateurs." The-Scientist.com, accessed November 11, 2020, https://www.the-scientist.com/critic-at-large/regulating-amateurs-39688; Bart Kolodziejczyk. "Do-It-Yourself Biology Shows Safety Risks of an Open Innovation Movement," *Ebics.net*, https://ebics.net/vignette-2-diy-biology-concerns/. Accessed November 11, 2020; Robert Bolton and Richard Thomas. "Biohackers: The Science,

the number of participants continue to expand and complex scientific tasks can be accomplished by anyone, then it would be only a matter of time before a biohacker was the cause of an accidental or deliberate biological event.

Examples of this heightened biorisk framing of DIYBio due to the ubiquity of science are prevalent in the literature and in policy. The 2010 Presidential Commission for the Study of Bioethical Issues report on synthetic biology and emerging technologies supported the view that DIYBio posed biosafety and biosecurity risks due to the community's interest in capabilities like synthetic biology. Prominent biosecurity experts like Michael Osterholm and Arturo Casadevall are both on record raising concerns that the DIYBio community may use online publications to create viruses in garage labs. Journal and news articles highlight how this community is not fully transparent to the public, which further exacerbates the biorisk concerns as technologies become further distributed and accessible to unsupervised individuals and groups.[112] There are even

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Politics, and Economics of Synthetic Biology," *Innovations: Technology, Governance, Globalization* 91, no. 2, 2014, 213 – 219; James Revill and Catherine Jefferson. "Tacit Knowledge and the Biological Weapons Regime." *Science and Public Policy*, 41, 2014, 597 – 610; Daniel M. Gerstein. "How Genetic Editing Became a National Security Threat." *The Bulletin*, https://thebulletin.org/2016/04/how-genetic-editing-became-a-national-security-threat/. Accessed November 11, 2020; John Wikswo, Stephen Hummel, and Vito Quaranta. "The Biohacker: A Threat to National Security." *CTC Sentinel* 7, no.1 2014, 8 – 11; and NASEM. *Preparing for Future Products of Biotechnology*. *NAP,* https://usbiotechnologyregulation.mrp.usda.gov/NASEM_Study.pdf. Accessed November 11, 2020.

[112] See *New Directions: The Ethics of Synthetic Biology and Emerging Technologies*. Washington DC: Presidential Commission for the Study of Bioethical Issues, 2010; Carl Zimmer, "Amateurs Are New Fear in Creating Mutant Virus," *The New York Times*, March 5, 2012, https://www.nytimes.com/2012/03/06/health/amateur-biologists-are-new-fear-in-making-a-mutant-flu-virus.html?auth=login-email; Thomas Landrain et al., "Do-It-Yourself Biology: Challenges and Promises for an Open Science and Technology Movement," *Systems and Synthetic Biology* 7, no. 3, 2013, 115-126, https://doi.org/10.1007/s11693-013-9116-4; Thomas E. Engells and Raina MacIntyre, "Do It Yourself Biology – Committed Hobbyists or Dangers to the Public Safety?" *Journal of Healthcare Protection Management* 32, no. 2, June 2016, 39 – 54; Todd Kuiken, "Should We Fear DIY Biologists' Use of Cutting-Edge Gene-Editing Technology?," *Scientific American*, March 18, 2016, https://www.scientificamerican.com/article/should-we-fear-diy-biologists-use-of-cutting-edge-gene-editing-technology/, *Security Implications of Synthetic Biology and Nanobiotechnology: A Risk and*

reports that DIYBio members were directly contacted by companies that had done security-related contract work for the United States government to explain their activities.[113]

Therefore, the focus is placed on the perceived limitless potential the DIYBio community has for growth and potential harm in the biorisk narrative due to the perceived ubiquity of success for complex scientific tasks and projects. However, there is empirical evidence drawing from the science and technology studies (STS) literature which indicates technical capabilities and tangible resources alone may not be sufficient to ensure success in this context. Rather, these scholars argue that technical capabilities should only compromise one part of a larger analysis: an analysis that considers socio-technical dynamics such as tacit knowledge and expertise, as well as organizational, managerial, social, and economic factors.[114]

Response Assessment of Advances in Biotechnology. Turin, Italy: United Nations Interregional Crime and Justice Research Institute (UNICRI), 2012; Jeanne Whalen, "In Attics and Closets, 'Biohackers' Discover Their Inner Frankenstein," *The Wall Street Journal*, May 13, 2009, https://www.wsj.com/articles/SB124207326903607931, and Andrew Hessel, Marc Goodman, and Steven Cotler, "Hacking the President's DNA," *The Atlantic,* February 19, 2014, https://www.theatlantic.com/magazine/archive/2012/11/hacking-the-presidents-dna/309147/. Accessed November 5, 2020.

[113] Jeanne Whalen, "In Attics and Closets, 'Biohackers' Discover Their Inner Frankenstein," *The Wall Street Journal*, May 12, 2009, https://www.wsj.com/articles/SB124207326903607931. Accessed March 10, 2021.

[114] See Vogel, *Phantom Menace or Looming Danger*, Loc 1291 – 1986; Iris Hunger, Jez Littlewood, Caitriona McLeish, Piers Millett, and Ralf Trapp, "Roundtable: The Future of Biothreat Governance," in *Biological Threats in the 21st Century*, London, UK: Imperial College Press, 2016, 431 – 450; Ben Ouagrham-Gormley, *Barriers to Bioweapons*, 2014, 17 – 63; Sonia Ben Ouagrham-Gormley and Kathleen M. Vogel, "The Social Context Shaping Bioweapons (Non)proliferation," *Biosecurity and Bioterrorism* 8, no. 1, 2010, 9 – 24; Sonia Ben Ouagrham-Gormley and Shannon R. Fye-Marnien. "Is CRISPR a Security Threat?". In *Defense Against Biological Attacks*, 233 - 251. Springer, Cham, 2019; Kathleen M. Vogel and Sonia Ben Ouagrham-Gormley, "Anticipating Emerging Biotechnology Threats: A Case Study of CRISPR," *Politics and the Life Sciences* 37, no. 2, 203 – 219; and Kendall Hoyt, *Long Shot: Vaccines for National Defense*, Cambridge, MA: Harvard University Press, 2012, Loc 529 – 858.

This dissertation has already mentioned the role of tacit knowledge and expertise and its impact on amateurs successfully using basic life sciences equipment and skills. However, tacit knowledge is not just about individual knowledge – achieving success in complex scientific tasks requires tacit knowledge and expertise to be built *within* and *between* all participants as well. In the context of biological weapons research and development, Ben Ouagrham-Gormley notes that achieving this type of knowledge creation, transfer, and use is exceptionally difficult. Further, Hoyt, Ben Ouagrham-Gormley emphasize how difficult it is to generate and pass along tacit knowledge due to its personal, local, geographically-bound, and "sticky" nature.[115]

The literature provides several organizational, managerial, social, and economic considerations that affect the success or failure of complex scientific tasks and projects. In terms of organizational components, Ben Ouagrham-Gormley notes that generating environments to optimize tacit knowledge creation, transfer, and use must be deliberately engineered. In addition, these engineered environments must include two key organizational characteristics: the ability for people to work closely and have freedom of movement to interact with others with minimal impediments and the mechanisms to allow different groups to interact and coordinate activities across all stages of a complex scientific endeavor.[116]

Further, this engineered organizational style requires a knowledgeable and active manager. Ben Ouagrham-Gormley highlights how important the role of the manager is

[115] See Hoyt, *Long Shot*, Loc 71 – 87; Ben Ouagrham-Gormley, *Barriers to Bioweapons*, 2014, 17 – 24; and Vogel, *Phantom Menace or Looming Danger*, Loc 1925.
[116] Ben Ouagrham-Gormley, *Barriers to Bioweapons*, 2014, 17 – 52.

along three dimensions in successfully navigating a complex scientific endeavor, including 1) Creating and maintaining a social environment that is conducive to promoting trust and community; 2) Encouraging transparency and interaction of project members across all the stages of the program; and 3) Functioning as an active interlocutor between external stakeholders and project staff to advocate for the program and acquire sustained, stable interest and funding.[117]

Social factors also play into creating an environment conducive to the successful completion of complex scientific tasks and projects. The root considerations for social factors are about building trust and familiarity within and between project members at all stages of a project. As Hoyt notes, building trust and familiarity between and amongst individuals is necessary to transfer tacit knowledge more easily.[118] Ben Ouagrham-Gormley digs in deeper and notes that trust and familiarity are necessary to not only ease tacit knowledge transfer, but to help project members see themselves as a part of a community – a community that works, communicates, and troubleshoots together despite coming from different backgrounds, specialties, locations, and cultures.[119]

Finally, economic factors play a significant role in the success of complex scientific tasks and projects. Having the finances to purchase the necessary equipment, materials, and reagents necessary to run a project is just one important economic factor to consider. Ben Ouagrham-Gormley also highlights how stable access to necessary items and equipment needs to be accounted for. Without stable access, project members may

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[117] Ibid., 45 – 46.
[118] Hoyt, *Long Shot*, Loc 87.
[119] Ben Ouagrham-Gormley, *Barriers to Bioweapons*, 46 – 48.

find their workflow interrupted, find they have less time to devote to the project, and even must deal with power struggles due to competition for scarce resources.[120]

The empirical evidence indicates that access to technical capabilities alone does not ensure that a complex scientific task or project will automatically result in success. Rather, tacit knowledge and expertise, as well as organizational, managerial, social, and economic factors also play significant roles in the outcome of complex scientific projects.

Unfortunately, assessing these tacit knowledge and organization, managerial, social, and economic elements in the DIYBio context is currently impossible with the existing literature. There is no rigorous analysis conducted of the DIYBio community lab landscape that captured these types of data. The most comprehensive survey to date is the 2013 Wilson Center survey of the global DIYBio community. The product generated from this survey was insightful in certain ways, it lacked information on how community lab members structured themselves, how leaders were chosen and what was expected of them, how people operated socially in these spaces, and how economic considerations played into the emergence and maintenance of community lab spaces.[121]

Nevertheless, what little academic literature that does exist on the community asserts that this community has very real limitations at present. One study argues that the community has yet to carry out a successful synthetic biology project due to three materials-related factors. First, funding shortages mean that the labs cannot purchase necessary components such as enzymes and prime biological materials such as synthetic

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[120] Ibid., 55 – 56.
[121] Daniel Grushkin, Todd Kuiken, and Piers Millet. *Seven Myths & Realities about Do-It-Yourself Biology*. Washington DC: Wilson Center, 2013.

DNA sequences. Second, the varying regulations across states and countries may prohibit amateurs from access to certain reagents and necessary materials. Third, technological limitations in areas such as computer-aided design (CAD) technologies make developing robust and optimized synthetic biology models difficult.[122]

Resolving Biorisk Assumption #3 – Community Labs and their Design

Therefore, a third factor that needs to be explored are how community labs are designed. In this dissertation, design refers to how community labs are organized, managed, and financed, as well as how people interact socially in these spaces to build camaraderie, trust, and a common culture. These factors, along with considerations for tacit knowledge and expertise will provide a holistic examination that will help test the assumption of the biorisk community that complex scientific tasks can be accomplished by anyone, anywhere, and at any time.

Separating Fact from Fiction – The DIYBio Community's Perspective

DIYBio Community History

The emergence of a DIYBio-like community was also not totally unforeseen by innovators and technologists that had ties to the security community. In 2000, Rob Carlson, Roger Brent, and Drew Endy filed a grant application to the U.S. Defense Advanced Research Projects Agency (DARPA) to discuss and develop a form of open-

[122] Thomas Landrain et al., "Do-It-Yourself Biology: Challenges and Promises for an Open Science and Technology Movement," *Systems and Synthetic Biology* 7, no. 3, 2013, 115-126, https://doi.org/10.1007/s11693-013-9116-4

source biology. Their vision was that this type of open-source biology could allow essentially what some DIYBio members do now: doing science in their homes.[123]

The DIYBio movement and its practices began to emerge during the 2000's: a time associated with significant technical, societal, and economic changes. Easing biology through the emergence of synthetic biology and rapidly decreasing costs of DNA sequencing and synthesis were the main technical contributors. Societally, there was a trend towards "hacking" and self-driven building projects within U.S. society at this time, which manifested through the rise of hackerspaces and the emergence of periodicals like *Make* magazine – a magazine that provided its subscribers with the tools, knowledge, and instructions to make technology do their bidding.[124] Economically, this period corresponds with individuals valuing entrepreneurship and innovation for personal and market gain and public funding decreases for universities.[125]

The DIYBio movement truly took off in 2008 in Cambridge, MA after mutual acquaintances connected Mac Cowell and Jason Bobe – two synthetic science enthusiasts. Mac Cowell was a graduate student who helped run the International Genetically Engineered Machine (iGEM) competition at MIT, and Jason Bobe was a director of the Personal Genome Project – a project seeking to help create and share public genome, health, and trait data. Their shared interest was in promoting the idea and

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[123] Ibid., 106.

[124] A famous milestone associated with DIYBio and *Make* magazine was a 2006 issue titled "Backyard Biology". This issue featured 9 backyard biology projects that people could do with household tools and materials, such as extracting and visualizing DNA.

[125] Morgan Meyers and Rebecca Wilbanks, "Valuating Practices, Principles and Products in DIY Biology: The Case of Biological Ink and Vegan Cheese," *Valuation Studies* 7, no. 1, 2020, 101 – 122.

practice of amateur biology – a reality they felt was possible due to the falling costs of DNA sequencing and know-how distribution through the internet.[126]

To this end, Bobe and Cowell created an online forum called DIYBio.org in 2007.[127] Even in the early days, this forum had hundreds of subscribers to its e-mail list.[128] Online conversations about the potential for amateur science transferred into a real-life meeting on May 24, 2008. Over 25 DIYBio enthusiasts gathered in-person for the first time at a local to learn about, discuss, and plan out the next steps of amateur biology.[129]

Genspace, the world's first DIYBio community lab, opened in 2010 in Brooklyn, New York. Other community spaces such as BioCurious in California, La Paillasse in France, and MadLab in the United Kingdom emerged in quick succession.[130] The rapid emergence of community labs across different countries caught the attention of policymakers starting in 2008 – 2009. The FBI was particularly concerned with the community given a startling rise in bioterrorism events around the globe that seemed to correspond with what helped make the DIYBio community possible: an increased

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[126] Prashant Nair, "Straight Talk with…Mac Cowell and Jason Bobe," *Nature Medicine* 15, no. 3, 2009, 230 – 232.
[127] Gabriela A. Sanchez Barba, "We Are Biohackers: Exploring the Collective Identity of the DIYBio Movement," *ResearchGate*, https://www.researchgate.net/profile/Gabriela-Sanchez-5/publication/284727537_We_are_Biohackers_Exploring_the_Collective_Identity_of_the_DIYbio_Movement/links/565845c808aefe619b20e07f/We-are-Biohackers-Exploring-the-Collective-Identity-of-the-DIYbio-Movement.pdf. Accessed March 13, 2021.
[128] Nair, "Straight Talk,", 231.
[129] Jason Bobe, "Don't Phage Me, Bro," *DIYBio*, https://diybio.org/2008/05/24/dont-phage-me-bro/. Accessed March 13, 2021.
[130] Landrain et al., "Do-It-Yourself Biology,", 117.

accessibility to life sciences material, knowledge, and equipment.[131] This led to a series of FBI-led initiatives that convened policymakers, law-enforcement, and DIYBio members to discuss safety, security, and to build a way for DIYBio practices to continue with minimal interference.[132]

For some DIYBio members and leaders, FBI interaction was appreciated and welcomed. These members saw the interactions as building a mutually-beneficial partnerships – the FBI had eyes and contacts within the community to act as informants in the event of suspicious or nefarious activity, and the DIYBio community could point to their cooperation with the FBI as a strong indicator that their activities were lawful to groups critical of the movement.[133]

For other DIYBio members and leaders, FBI interactions with the community was viewed as unnecessary and intrusive. This was particularly true for DIYBio members and leaders based in Europe, who suspected the motives and actions of the FBI. These suspicions were rooted in an incident in 2004, when the FBI had raided the home of bioartist Steve Kurtz. Due to the presence of biological equipment and bacterial samples in his home, Kurtz was initially charged with bioterrorism. While all charges were eventually dropped, the FBI's actions were viewed unfavorably by global members of the DIYBio movement.[134]

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[131] Hanno Charisius, Richard Friebe, and Sascha Karberg, "Becoming Biohackers: The Long Arm of the Law," *BBC Future*, https://www.bbc.com/future/article/20130124-biohacking-fear-and-the-fbi. Accessed March 13, 2021.

[132] Howard Wolinsky, "The FBI and Biohackers: An Unusual Relationship," *EMBO Reports* 17, no. 6 2016, 793 – 796.

[133] Tocchetti and Aguiton, "Is an FBI Agent a DIY Biologist,", 825 – 853.

[134] Wolinsky, "The FBI and Biohackers,", 793.

The rift in how FBI interaction with the DIYBio community highlighted a need for regional DIYBio communities to convene, discuss, and plan next steps in how to proceed with what was rapidly becoming a global movement. To this end, the U.S. and European DIYBio communities came together in a series of "congresses" in the 2011 – 2012 period. DIYBio representatives from U.S. and Europe discussed and generated a code of conduct – a framework to identify community values and the practices that follow from them. The values and practices the U.S. and European representatives arrived at were practically identical. They both emphasized the need for open access to biotechnology information and technologies, transparency of ideas and practices, education of the public to raise awareness of the future benefits of biotechnology, safety in lab practices, and using biotechnology only for peaceful purposes.[135]

Since 2008, the community has grown rapidly across the United States, Europe, and the rest of the globe. In 2017, a Brookings report noted that the number of participants and shared lab spaces were rapidly increasing globally. In the United States, there were over 50 DIYBio spaces with estimates of nearly 30,000 enthusiasts, participants, and followers. In Canada, there were estimated to be 12 active biohacker spaces with over 2,5000 members. The report also identified 60 DIYBio groups around Europe, 9 in Oceania, 22 in Asia, 16 in Latin America, and even several in Africa.[136]

The DIYBio community has also found ways to foster communication and interaction between members both regionally and globally. DIYBio.org and its forum

[135] "Codes," DIYbio, March 18, 2018, https://diybio.org/codes/.
[136] Bart Kolodziejczyk, "Do-It-Yourself Biology Shows Safety Risks of an Open Innovation Movement," *Brookings*, https://www.brookings.edu/blog/techtank/2017/10/09/do-it-yourself-biology-shows-safety-risks-of-an-open-innovation-movement/. Accessed March 13, 2021.

continues to be one way that members share ideas, interact, and collaborate. There have also been efforts to hold regional and global DIYBio conferences to foster community by meeting in person, sharing ideas and values, and discussing what direction(s) the DIYBio community should take going forward.[137]

Finally, with the emergence and continued impact of the COVID-19 pandemic, some parts of the community have come together to build an online platform known as Just One Giant Lab (JOGL). This platform creates a virtual space to allow members to propose, research, and run citizen-science projects meant to address gaps in the global COVID-19 response.[138]

DIYBio Community Narrative

The DIYBio community has repeatedly denied and attempted to reframe the narrative away from perceptions of suspicion and danger. To this day, biohackers and amateur biology enthusiasts maintain that they follow an informal code of ethics self-generated within the DIYBio community during its inception in 2008. This code, while

[137] The DIYBio community has two main conferences. The first of these is "Biohack the Planet" – a conference hosted in the San Francisco Bay Area (U.S.), and is organized by Josiah Zayner and his biotech company, The Odin. The second of these conferences is "Global Bio Summit" – a conference hosted in the MIT Media Lab at Cambridge, MA (U.S.), and is organized by MIT staff and DIYBio volunteers. More details for both can be found at http://biohacktheplanet.com/ and https://www.biosummit.org/.

[138] The JOGL platform came online in April, 2020 – roughly around the start of the recognition of COVID-19 as a global pandemic. Founded by former La Paillasse member Thomas Landrain, it considers itself an open, distributed online mobilization platform to allow interested parties to help fix global problems. During COVID, many of its projects have included creating low-cost COVID-19 diagnostics tests, testing the efficacy of 3-d printed masks, and other such tasks. More details can be found at https://jogl.io/.

not binding, places the onus on members to "be safe, do not damage anything, and do not damage anyone…physically, mentally, or emotionally."[139]

The efforts of the community are not just limited to internal actions like generating and following a code of ethics. From 2009 to the present day, government agencies and science non-profits have reached out directly to the DIYBio community to participate in a series of workshops and conferences on addressing the safety and security risks of synthetic biology and amateur science practices. Rather than rebuff these invitations, prominent DIYBio community individuals like DIYBio.org founders Jason Bobe and Mac Cowell, as well as the leaders of several community labs, went to these events. These representatives emphasized how the DIYBio community could benefit science innovation and grass-roots science education while introducing minimal risk to biosafety and biosecurity concerns.[140]

In 2018, Genspace co-founder and prominent DIYBio community member Daniel Grushkin wrote an op-ed in response to Baumgaertner's 2018 article to address what he saw as misconceptions of the DIYBio community.[141] He presented a significantly different picture of the DIYBio community compared to Baumgaertner's: an open, responsible community that enables members to explore interests, build and execute projects together, and empower citizens by opening access to the life sciences. Grushkin

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[139] Markus Schmidt, "Diffusion of Synthetic Biology: a Challenge to Biosafety," *Systems and Synthetic Biology* 2, no. 1-2, 2008, 1-6, https://doi.org/10.1007/s11693-008-9018-z.
[140] Edward Lempinen, "FBI, AAAS Collaborate on Ambitious Outreach to Biotech Researchers and DIY Biologists," American Association for the Advancement of Science, March 31, 2011, https://www.aaas.org/news/fbi-aaas-collaborate-ambitious-outreach-biotech-researchers-and-diy-biologists.
[141] "Genspace New York's Community Lab," Genspace, March 17, 2018, https://sphere.diybio.org/labs/genspace/.

cites self-regulatory practices and pre-emptive actions in the DIYBio community to further his narrative that the community is responsible and safe. These practices and actions reiterated past actions that DIYBio community members have highlighted, including a code of ethics, connecting community members with professional biosafety officers, and working with law-enforcement institutions like the FBI. This op-ed presented the DIYBio community as a public resource whose benefits far outweigh the negatives such as several acts of self-experimentation done by biohackers.[142]

To publicize and emphasize its focus on safety practices, the DIYBio community provided a written account of a DIYBio biosafety course with professional biosafety experts. This write-up, which was hosted on the Baltimore UnderGround Science Space (BUGSS) website, discussed an in-person biosafety bootcamp course for solo and community lab DIYBio members. Organized by Genspace co-founder Dan Grushkin and DIYBio expert Todd Kuiken and funded through the Open Philanthropy Project, this course was done in collaboration with the American Biological Safety Association (ABSA) – an internationally-recognized organization that serves as a forum to generate and share best practices in the areas of biosafety and biosecurity. Over a three-day period, these biosafety professionals used a combination of lectures, exercises, hands-on practice, and question-and-answer sessions to help DIYBio participants figure out what they should consider when building, implementing, and refining biosafety practices in their unique spaces. This course highlights attempts on the part of the community to reach out

[142] Grushkin, Daniel. "Biohackers Are About Open-Access to Science, Not DIY Pandemics. Stop Misrepresenting Us," *STAT*, June 4, 2018, https://www.statnews.com/2018/06/04/biohacker-open-access-science/. Accessed 01/05/2020.

to recognized organizations for both training and support in practicing the life sciences safely in unconventional spaces.[143]

Capabilities assessments continue to be a significant concern when it comes to the DIYBio community. Unfortunately, this is not helped by the fact that the most comprehensive report to date of the DIYBio community dates to 2013, which exacerbates concerns of the group and interferes with an analyst's ability to make good biorisk assessments. With this caveat, the2013 Wilson Center study of the U.S. DIYBio community appears to show that the capability to create a deadly insect or virus is far beyond the capabilities of a typical DIYBio member or community lab. Rather, most DIYBio members appear to still be learning the basics of biology and lab skills – basics that include learning how to use equipment in the lab, to pipette liquids, make media to cultivate BSL-1 organisms like baker's yeast and non-pathogenic *E. coli*, and follow and execute protocol successfully.[144]

As discussed previously, this need for the majority of DIYBio members to gain basic biology knowledge and skills also helps explain why DIYBio community labs fail to adopt cutting-edge technologies in their settings. Adoption of cutting-edge technologies like the gene-editing technique called CRISPR appear slow in the community lab setting. More advanced labs like the Baltimore UnderGround Science Space (BUGSS), Genspace, BioCurious, and Biotech without Borders have offered

[143] "Checking Ourselves Before Wrecking Ourselves: Co-Evolving Innovation and Safety in the DIYBio community". *BUGSS*, October 10, 2019, https://bugssonline.org/community/diybio-biosafety/. Accessed 11/04/2020.
[144] Grushkin, Kuiken, and Millet, "Seven Myths and Realities,", Wilson Center, 2013, https://www.wilsoncenter.org/publication/seven-myths-and-realities-about-do-it-yourself-biology-0.

workshops using pre-assembled kits to teach this technique, but very few projects in these spaces actively house projects that require its use.

Clash of the Narratives – Breaking the Dichotomy of Malign versus Benign Community

Taken at face value, the assessment that national security analysts arrive at makes sense. The risks associated with DIYBio appear to outweigh the infringement upon an individual's autonomy to learn and tinker with biotechnology in an unregulated space. From a biosafety standpoint, a DIYBio community member's lack of formal biosafety training means that members may not have the hands-on training to safely handle and contain the micro-organisms, biological materials, chemical reagents, and the equipment they are working with.[145] In turn, a DIYBio community member's lack of hands-on safety training may have negative repercussions for themselves, their immediate surroundings, and their community.

Additionally, researchers in both traditional and DIYBio contexts are developing new protocols and equipment that make it cheaper, easier, and faster to develop everything from plasmids and bacteriophages to full genomes. These protocols and equipment are widely available thanks to the global nature of the internet. Therefore, bioterrorism appears to be easier than ever from a biosecurity standpoint.[146]

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[145] Centers for Disease Control and Prevention. "Biosafety in microbiological and biomedical laboratories (BMBL).", Washington, DC: CDC Publications, p. xxiii

[146] For examples, see Warrick, Joby. "Custom-built pathogens raise fears of bioterror. *The Washington Post*, July 31, 2006, https://research.*lifeboat*.com/tara.htm and Chyba, Christopher F., and Alex L. Greninger. "Biotechnology and Bioterrorism: An Unprecedented World." *Survival* 46, no. 2, 2004, 143-162.

However, the assumptions that the biorisk narrative utilizes oversimplifies the DIYBio phenomenon. This oversimplification then exaggerates the risk the group represents from a biorisk threat angle. Rather than unknown motivations, the DIYBio community has very set motivations and values for operation that then limit their activities. While the language used to express these motivations and values are typically anti-establishment and disruptive in spirit, the change that the DIYBio movement seeks to bring to the world is one done through non-violent means. Further, the community is not a limitless potential for risk since it faces very real limitations from factors like tacit knowledge and expertise, as well as organizational, managerial, social, and economic factors. Finally, the existence of a *wider* pool of life sciences practitioners outside of traditional academia, industry, and government does not mean that the life sciences are fully democratized and accessibility equally to everyone in the world. Again, there are very real barriers that limit life sciences access to a significant portion of the globe and even the United States, including the quality of equipment and tools, as well as expertise and information access barriers.

The biorisk and DIYBio narratives offer diametrically opposed views of the DIYBio community. While each of these narratives provide valuable insights, they exist in parallel with limited attempts at entering in communication with each other. This parallel dynamic effectively siloes the biorisk and DIYBio communities from each other. In turn, these silos create an echo chamber effect where dominant narratives of DIYBio are amplified, reinforced, and perpetuated within the silo.

For the biorisk community, the silo reinforces and perpetuates the narrative that DIYBio represents a significant threat to biosecurity and biosafety. In an era where bioterrorism appears to be trending upwards, it is a frightening prospect for unsupervised amateurs, like those in the DIYBio community, to have access to life sciences equipment, materials, protocols, and knowledge. In addition, the DIYBio community is noted for using language and promoting actions that can be construed as countercultural, anti-establishment, and disruptive. Third, the biorisk community believes that the DIYBio community can take advantage of de-skilling and technical capabilities to successfully perform and accomplish complex scientific feats anywhere, and at any time.

For the DIYBio community, the silo reinforces and perpetuates the narrative that DIYBio is a force of unequivocal good for the world. The DIYBio community views its motivations for democratizing technology as good, desirable, and a vehicle to help all people engage, explore, invent, and empower themselves through biology. The DIYBio community narrative also emphasizes its success in eliminating biorisks through establishing a common code of ethics and values, oversight mechanisms like review boards for projects, repercussions for unacceptable behavior, and engaging with outside entities like the FBI and ABSA. Third, the DIYBio community narrative emphasizes how the activities of its members are limited both by the types of projects people engage in and their capabilities as a predominantly amateur science-driven movement.

What neither side acknowledges is that the siloed nature of both the biorisk and DIYBio communities makes each narrative incomplete – neither offers a holistic view of the benefits and risks of the DIYBio community. In the case of the biorisk narrative, this includes a profound lack of understanding the DIYBio community in terms of its capabilities, motivations, and ability to do complex science. In the case of the DIYBio narrative, this includes a tendency to underplay the shortcomings of the community in terms of its tendency to exaggerate its capabilities, underemphasize the potential for accidents where amateurs interact with volatile chemicals, and underplay the risks associated with distributed technologies, de-skilling, and future advances in the life sciences.

Therefore, the long-standing nature of the two narratives and their lack of evolution over time exposes three key issues. First, it shows that individuals perceive the benefits and risks of the DIYBio community based upon their individual expertise. The biorisk community paints an overly scary picture of the threat that the DIYBio community presents by focusing solely on the biosafety and biosecurity risks of the DIYBio community. In turn, the DIYBio community on the other hand paints a near-angelic picture of its community by focusing on its own potential benefits to society, scientific ventures, and technological innovation with almost no discussion concerning biorisk threats. Second, it highlights how national security/safety stakeholders and the DIYBio community do not effectively communicate with each other. Finally, it displays how stakeholders will make no progress to understand the true benefits and risks of the DIYBio community if matters continue as they have in the past: lots of speculation, but little analysis based on research and empirical evidence.

Researchers need empirical data on the DIYBio community to break this cycle and to separate the malign from the benign. Past researchers have focused on quantitative analyses to gauge the size, interests, and activities of the DIYBio community in the United States. The most prominent and comprehensive of these has been a 2013 Wilson Center study.[147] DIYBio community leader Daniel Grushkin, NC State Academic Todd Kuiken, and biosecurity expert Piers Millett used an online survey posted on DIYBio.org from January through March of 2013 to understand the community's demographics, details related to the types of DIY experiments individuals were conducting, as well as where individuals were conducting these experiments.[148]

Therefore, it is essential to gain a deeper understanding of the DIYBio community and its effects on the biorisk threat landscape: to separate the fact from the fiction in both narratives. This dissertation focused on gaining insight of U.S. DIYBio community labs in three areas to help resolve issues with the assumptions of the biorisk narrative: the **drives**, the **design,** and the **degree of life sciences democratization** of the DIYBio community. This data framework will henceforth in the dissertation be referred to as the "3Ds". The next chapter delves into the methodology of this dissertation, which summarizes the history, activities and characteristics of the community labs researched in this dissertation, as well as describing the methodology for this dissertation.

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[147] Daniel Grushkin, Todd Kuiken, and Piers Millet. *Seven Myths & Realities about Do-It-Yourself Biology*. Washington DC: Wilson Center, 2013.
[148] Ibid.

CHAPTER THREE – DIYBIO COMMUNITY LAB ACTIVITIES, CHARACTERIZATION, AND DISSERTATION METHODOLOGY

Introduction

To better understand the community, a great place to start is with what is currently factually known of the community. This chapter will focus on showing the existing state of knowledge concerning DIYBio community labs, including their activities, values and philosophies, and the types of people drawn to these spaces. This chapter will then provide brief summaries on the 9 specific labs in the U.S. this dissertation focused on for further insights. Finally, this section concludes with the methodology for this dissertation, including 1) the choosing and gaining access of sites; 2) gathering observation data during on-site field research and interview data through online video chat interviews; 3) data compilation and analysis through the qualitative data analysis software NVivo; and 4) using the generated data analysis to compare with expectations from existing terrorism and STS literatures as an analytic framework to assess how DIYBio community labs are changing the biorisk threat landscape.

DIYBio Community Labs

Overview

DIYBio is a global movement which consists of a broad, de-centralized network of independent and small-group practitioners. What has predominantly captured the attention of the biorisk community is the independent biohacker: someone who performs scientific tasks and projects at home on their own.[149] These makeshift labs incorporate an eclectic mix of second-hand lab equipment purchased from online auction sites, existing tools repurposed for lab practices, and even DIY equipment meant to replace the purpose or function of classic lab equipment. DIYBio member Kay Aull is the prime example of this type of independent hacker. An MIT graduate in biological engineering, Kay Aull obtained some specialized laboratory equipment from eBay, repurposed a rice cooker to acquire distilled water, generated some homemade devices to develop a DIY genetic test for hemochromatosis.[150]

Starting in 2010, mixed groups of amateurs and professional biologists working in community labs have emerged and become more common. As mentioned previously, community labs are shared spaces which house a combination of second-hand equipment, home-made equipment, materials, and reagents. These community labs serve several purposes, including encouraging the discussion, practice, education, and exploration of science outside of academia, industry, and government.[151]

These community labs are also largely influenced in terms of their personality, character, interests, and capabilities by the people that operate and socialize in these spaces.[152] The individuals that these spaces attract can significantly vary depending on their ideologies and initial activities. Genspace was the world's first community lab founded in 2010 by co-founders with varied backgrounds in molecular biology,

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[149] Scheifele and Burkett, "The First Three Years of a Community Lab," 81.
[150] Morgan Meyer, "Build Your Own Lab: Do-It-Yourself Biology and the Rise of Citizen Biotech-Economies," *Journal of Peer Production* 2, no. 4, 2012, 1 – 4.
[151] Scheifele and Burkett, "The First Three Years of a Community Lab," 81 – 82.
[152] Ibid.

journalism, art, and design[153]. While Genspace's initial forays were largely in researching, starting, and running ambitious biotech, they also incorporated an emerging bio-art portfolio as the space attracted artists looking to leverage biology as a new medium in their artistic endeavors.[154]

Further, while Genspace has continued this tradition of biotech and art, it has experienced significant changes since its opening, including moving locations, changes in leadership, and refocusing its mission and core values to really look at the concept of democratization from a social justice and inclusivity lens. These changes have resulted in some changes in the types of activities and courses Genspace offers, including the addition of seminars and events that focus on the intersection of science, race, and society. This snapshot of Genspace highlights how the participants and values of community labs change and evolve over time and can have a significant effect on the people and activities that happen in these spaces.[155]

While independent and community lab practitioners operate in different spaces, the existing literature indicates DIYBio community members engage in four categories of activities. In this research, these activities are referred to as the "4Es": **exploration, education, empowerment, and entrepreneurship**.

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[153] "Genspace NYC," *NYC Service.gov*, 2021, https://www.nycservice.org/organizations/index.php?org_id=3721. Accessed March 20, 2021.
[154] Callie Clayton, "Visualizing the Invisible," *RISD Maharam Steam Fellowship*, June 22, 2016, https://risdmaharamfellows.com/2016/06/22/visualizing-the-invisible-genspace-callie-clayton-bfa-textiles-17/. Accessed March 20, 2021.
[155] Danya AbdelHamedi, Angela Armendariz, and Beth Tuck, "Genspace 2019 Annual Report: Evolving New York City's Life Sciences Ecosystem," *Genspace*, https://static1.squarespace.com/static/588b7cc315d5dbdea1425e5e/t/5f21d1183efd773bf445dbe4/1596051740088/Genspace+Annual+Report+2019.pdf. Accessed March 20, 2021.

Activity Category #1 - Exploration

In terms of **exploration**, community members run experiments and conduct research to **explore themselves and their environment**. These experiments may take place in community labs (dedicated labs with pooled resources where people collaborate) or in private homes.[156] Even on the cheap, DIYBio labs in a private residence may cost a few thousand dollars to set up.[157] Therefore, the access to more powerful equipment at a lower per capita cost and the sharing of expertise makes community laboratories an increasingly popular DIYBio venue at present.[158]

Most of these efforts consist of scientific practices where amateurs learn basic biotechnology techniques. Many of these aspirational or amateur scientists end up learning most of their lab skills from the founders and community lab leads. These founders and community lab leads are mostly individuals with undergraduate to PhD-level education in the life sciences.[159]

These amateur scientists then apply these learned techniques to personally experiment and tinker with their environment – everything from compiling observational data and analysis to working with the building blocks of life: DNA, RNA, proteins, and

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[156] Albert C. Lin, "Herding Cats: Governing Distributed Innovation," *North Carolina Law Review* 96, no. 4 ,2018, 945 – 1012, https://scholarship.law.unc.edu/nclr/vol96/iss4/2

[157] Ledford, "Life Hackers," 2010, 650-652

[158] Grushkin, Kuiken, and Millett, *Seven Myths & Realities*, 2013, 6 - 7

[159] For examples, see "Staff and Board," Baltimore Underground Science Space, accessed June 12, 2020, https://bugssonline.org/staff-and-board/, "People," Genspace, accessed June 12, 2020, https://www.genspace.org/staff-1, "About," BosLab, accessed June 12, 2020, https://www.boslab.org/about., "Team," Biotech Without Borders, accessed June 12, 2020, http://www.biotechwithoutborders.org/our-team, "About Us," BioCurious (November 19, 2012), https://biocurious.org/about/, "About SoundBio Lab," SoundBio Lab, accessed June 12, 2020, https://sound.bio/about., and Danielle Venton, "The Truth About DIY Bio Labs," KQED, November 14, 2016, https://www.kqed.org/futureofyou/274583/there-are-lots-of-scary-things-in-the-world-but-diy-bio-labs-arent-one-of-them.

non-pathogenic organisms like baker's yeast and certain strains of *E. coli*. Some of these experiments include DNA extraction or the isolation of bacteria with household tools and products. Others include novel applications with entertainment value, including the research and development of a kit to genetically engineer yeast to glow: presenting a fluorescent beer to friends at a party is a definite conversation starter.[160]

While the general sophistication level of these types of experiments are equivalent to those of an advanced high-school biology laboratory, the lack of sophistication should not be mistaken for a lack of creativity or innovation. DIYBio individual and group projects include biosensors to detect melamine contamination, a non-toxic alternative to commercial printer ink called biological blue ink, mapping the geographic location of various microbial strains, using DNA samples to get an understanding of the distribution of life that lives in prominent geographic landmarks, and rewriting the life sciences' body of scientific protocols to make them more appropriate for use in more amateur settings.[161]

Some more advanced members of the DIYBio community, often those with graduate degrees in traditional life sciences disciplines like microbiology and biochemistry, engage in projects that go beyond developing basic techniques and tinkering with DNA. Two popular projects that researchers often highlight are the Vegan

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[160] For examples, see "Barcoding the Harbor," Baltimore Underground Science Space, 2019, https://bugssonline.org/innerharbor/, "Genetically Engineer Any Brewing or Baking Yeast to Fluoresce," The ODIN, 2020, https://www.the-odin.com/ge-yeast/, "Open Night: PCR & Pizza," DIYBio, 2017, https://diybio.org/2017/01/, "The Kombucha Sequencing Project – Counter Culture Labs," Counter Culture Labs, 2017, https://sites.google.com/site/counterculturelabs/projects/project-ideas/the-kombucha-sequencing-project, and "Projects," MetaSUB, 2020, http://metasub.org/city-sampling-day/.

[161] Thomas Landrain, Morgan Meyer, Ariel Martin Perez, and Remi Sussan. "Do-It-Yourself-Biology: Challenges and Promises for an Open Science and Technology Movement," *Systems and Synthetic Biology*, 7, 2013, 115 – 126

Cheese Project, which leverages gene-editing technology to create yeast cells that can produce milk protein, and the Open Insulin Project, which is an attempt to develop a protocol for the low-cost production of insulin.[162] Other projects on the more sophisticated end of the spectrum include developing cheaper medical diagnostics with local and easy-to-procure components.[163]

Not all these projects use in-house equipment. For example, BioWeatherMap takes advantage of cheaper, faster, and more accurate gene sequencing services. DIYBio founder Jason Bobe, along with leading synthetic biologists George Church and Tom Knight, leverages the global nature of DIYBio to teach amateur scientists how to take samples from their local environment and submit them to gene synthesis companies for sequencing. This project aims "to become a platform to enable distributed environmental sensing capabilities, with major impacts in biodiversity, public health, and biosurveillance."[164] More modern projects like the MetaSUB "Global City Sampling Day" project also leverage the global nature of the DIYBio movement to collect samples for processing and sequencing at MetaSUB – an initiative based in Cornell University that aims to develop a detailed microbe map of cities around the world.[165]

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[162] For examples, see Marcus Wohlsen, "Cow Milk Without the Cow Is Coming to Change Food Forever," *Wired* June 6, 2017, https://www.wired.com/2015/04/diy-biotech-vegan-cheese/, Lisa Martin, "Oakland's Open Insulin Project Aims to Disrupt Diabetes: Make:" *Make*, March 15, 2017, http://makezine.com/2017/03/16/open-insulin-project-aims-disrupt-diabetes/, and Margaret Talbot, "The Rogue Experimenters," *The New Yorker*, May 25, 2020, https://www.newyorker.com/magazine/2020/05/25/the-rogue-experimenters.

[163] Conor M. W. Douglas and Dirk Stemerding, "Governing Synthetic Biology for Global Health through Responsible Research and Innovation," *Systems and Synthetic Biology* 7, no. 3, 2013, 139-150, https://doi.org/10.1007/s11693-013-9119-1.

[164] "BioWeatherMap.org", *bioweathermap.org*, accessed 07/02/2018: http://www.bioweathermap.org/

[165] "Homepage," MetaSUB, 2020, http://metasub.org/.

Activity Category #2 - Education

DIYBio members also **educate themselves, their local neighborhoods, and international communities.** Just as a basic understanding of physics is necessary to create a simple paper plane, a basic understanding of biology is necessary to tinker with well-defined organisms and their compositional elements. Community labs functions as a primary education center for their local communities on scientific matters due to two factors. The first factor is that community labs often have more equipment than garage labs or independent biohackers. The second factor is that academically-trained biologists, typically at a PhD level, either founded or hold leadership roles in these spaces.[166]

In these spaces, trained biologists can teach amateurs and the curious the basics of biology. However, the diverse technical backgrounds of individuals that compose the DIYBio community also means that members have access to a variety of informational sources to learn about areas such as chemistry, data science, engineering, and other disciplines associated with the modern study of life sciences.

Members can also gain knowledge beyond the social resources these spaces offer. Many community lab spaces can offer print resources for members to peruse. These print resources include libraries filled with textbooks, journals, magazine articles, pamphlets,

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[166] For examples, see "Staff and Board," *Baltimore Underground Science Space*, https://bugssonline.org/staff-and-board/. Accessed June 12, 2020; "People," *Genspace*, https://www.genspace.org/staff-1. Accessed June 12, 2020; "About," *BosLab*, https://www.boslab.org/about. Accessed June 12, 2020; "Team," *Biotech Without Borders*, http://www.biotechwithoutborders.org/our-team. Accessed June 12, 2020; "About Us," *BioCurious* https://biocurious.org/about/. Accessed June 12, 2020; "About SoundBio Lab," *SoundBio Lab*, https://sound.bio/about. Accessed June 12, 2020; and Danielle Venton, "The Truth About DIY Bio Labs," *KQED*, November 14, 2016, https://www.kqed.org/futureofyou/274583/there-are-lots-of-scary-things-in-the-world-but-diy-bio-labs-arent-one-of-them.

and printed protocols that community lab leadership acquire through companies, generate on their own based on their own expertise, or print from online sources.

Finally, members can gain knowledge independently or with community lab guidance through digital sources – sources available through audio, video, and/or internet resources. This includes digital versions of print media, as well as multimedia platforms to communicate information including audio and video materials such as YouTube or emerging visual journals such as the Journal of Visual Experiments (JoVE).

Sharing information through these three types of resources - social, print, and digital - is fundamental to the DIYBio community: a community that holds open access and transparency as some of its key values.[167] To this end, DIYBio members circulate print and digital sources to interested parties and the public alike. In community labs, DIYBio leaders and members offer classes to community lab members and the public alike. These classes can focus on life sciences information, training workshops on lab practices and techniques, and even encourage individuals and groups to develop their own projects. While many of these classes charge fees to cover the cost of materials and other logistical concerns, most of these events do not require an individual to identify as a DIYBio member – a local community individual interested in science or curious about an event is more than welcome to attend.

This information sharing also extends to international communities. Sharing with the international community is primarily done digitally, where project research and

[167] Elliot Roth, "A Guide to DIYbio (Updated 2019)," *Medium*, July 14, 2019, https://medium.com/@ThatMrE/a-guide-to-diybio-updated-2019-abd0956cdf74.

findings are submitted to online repositories such as DIYBio webpages to even contributions towards NIH gene sequence databases. In addition, DIYBio members have organized conferences and summits where the global DIYBio community comes together to connect, brainstorm, and share developments in their respective research efforts. Prime examples include the California-based *Biohack the Planet*, a conference to "organize a community around learning and discovering…[to] share…with each other", as well the Boston-based Global Community Bio Summit, where "the global community DIY biologists/community biologists/biohackers/biomarkers and members of independent and community laboratories [can] convene, plan, build fellowship, and continue the evolution of [their] movement."[168]

Activity Category #3 - Empowerment

DIYBio members also use their exploration and education **to empower themselves and others** to address issues that uniquely appeal to each individual member. Some local DIYBio projects can help with individuals identify whether the product they purchase is genuine. For example, some DIYBio projects use gene sequencing and bioinformatics for confirmation purposes, such as determining whether the fish a person purchases at the market is as advertised.[169] Other projects use similar techniques for

[168] For examples, see "BIOHACK THE PLANET 2020," A Biohacker Conference, 2019, http://biohacktheplanet.com/ and "Global Community Bio Summit 4.0," 2020, https://www.biosummit.org/

[169] Linda Rodriguez McRobbie, "What's Really in That Tuna Roll? DNA Testing Can Help You Find Out," *Smithsonianmag.com*, https://www.smithsonianmag.com/science-nature/whats-really-in-that-tuna-roll-dna-sequencing-180964850/. Accessed July 29, 2018.

attributional purposes, such as using dog saliva samples to determine and act against negligent dog owners who fail to pick up their dog's poop.[170]

Other empowerment activities can have broader environmental implications. For example, the Vegan Cheese project could provide a real cheese alternative to milk pumped from cows if successful in both concept and scaling production. Not relying on cows for cheese would address existing animal cruelty issues, be good for the environment, and allow a broader population to consume dairy products. Further, it would serve as a proof of concept with positive implications for the United States bioeconomy by generating a new market through biotechnology. Finally, it would also have positive implications for agricultural production lines and agricultural security if well-protected cell foundries could produce milk proteins, as opposed to historically vulnerable supply chains like cows and cow-derived products.

These empowerment activities can also have a direct impact on human health issues. In Project BioWeatherMap, citizen scientists start by collecting environmental samples which include swabs from surfaces and crevices, plant materials, and soil. Citizen scientists submit these samples to gene sequencing companies, who then sequence the sample and provide a report back to the citizen scientist. The submitter can then post the characteristics and results of the sample online for others to see. Project BioWeatherMap is expected to enhance existing biosurveillance efforts since it generates a more comprehensive understanding of the environment.[171] Other projects offer hope to

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[170] Lisa C. Ikemoto, "DIY Bio: Hacking Life in Biotech's Backyard," *UC Davis Law Review* 51, no. 2, 2017, 539 – 568

[171] "BioWeatherMap.org", *bioweathermap.org*, accessed 07/29/2018: http://www.bioweathermap.org/

those that are dependent on Mylan's expensive EpiPen: an epinephrine auto-injector system that now costs upwards of $300 - 600 for two uses.[172] Groups such as the DIYBio fringe group known as the Four Thieves Vinegar collective is using free/open chemistry with open source hardware to develop a $30 DIY alternative called the Epipencil for consumer use.[173]

Collaborations between DIYBiologists can also generate local solutions for complex issues. For example, an Indonesian DIYBio lab space collaborated with partners in Switzerland to develop multiple products meant to address water quality issues for the Indonesian people in Yogyakarta. These products included the development of an easy-to-do water sampling protocol of the local river and a digital map of the river to track water quality trends.[174]

Activity Category #4 - Entrepreneurship

Finally, an emerging trend in DIYBio is **to pursue entrepreneurial ventures**. DIYBio community labs often serve as incubators and spaces to test, develop, and prototype new ideas and products. In the beginning of DIYBio activities in the early 2000's, projects that produced novelties were highly valued and engaged the public's imagination. The famous "Glowing Plant Project", where a team of DIYBio members

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[172] "Mylan to Launch First Generic to EpiPen Auto-Injector at a List Price of $300 per Two-Pack Carton, a More than 50% Discount to the Brand Product," *Newsroom.Mylan.com*, http://newsroom.mylan.com/2016-08-29-Mylan-to-Launch-First-Generic-to-EpiPen-Auto-Injector-at-a-List-Price-of-300-per-Two-Pack-Carton-a-More-than-50-Discount-to-the-Brand-Product. Accessed November 6, 2018.
[173] Cory Doctorow, "Four Thieves Vinegar Collective: DIY EpiPens Were Just the Start," *BoingBoing.net*, https://boingboing.net/2018/07/27/theft-to-prevent-murder.html. Accessed July 29, 2018.
[174] Cindy Lin Kaiying and Silvia Lindtner. "Legitimacy, Boundary Objects & Participation in Transnational DIY Biology," *Proceedings of the 14th Participatory Design Conference: Full Papers* 1, 2018, 171- 180

tried to create a plant that luminesced, originated from the BioCurious community lab in Sunnyvale, California. While the project ultimately failed due to administrative, logistical, and technical issues, it has left its mark in DIYBio history as the first entrepreneurial DIYBio project that was funded through a massively successful crowdfunding campaign.[175]

Recent DIYBio entrepreneurial ventures continue to have novel elements, but also focus on developing practical products with functional proof-of-concept creations. Some of these entrepreneurial ventures target DIYBio community members directly. Companies like THE ODIN and Bento Bioworks create tools to enhance the capabilities of solo practitioners and community lab members alike. Bento Bioworks' "Bento Lab" is equipped with a PCR thermocycler, a centrifuge, and a gel electrophoresis box to allow DIYBio members to go from DNA replication to DNA analysis in one compact product. On the other hand, THE ODIN's genetic engineering home lab kit "provides all the equipment, reagents, and materials…to get started in molecular biology and genetic engineering".[176,177]

Other entrepreneurial ventures are targeted at the public or other, specific audiences. A popular project for DIYBio members is to research new biomaterials for alternatives to everything from building materials to clothing fabrics and dyes. Like many traditional labs, DIYBio members are also looking at ways to address a variety of societal

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[175] Ariel Schwartz, "One of the Most Controversial Kickstarter Campaigns in History is Dead – Here's the Product that Actually Got Made," *Business Insider*, https://www.businessinsider.com/glowing-plant-kickstarter-campaign-orbella-moss-2017-8. Accessed July 29, 2018.
[176] "Your DNA Analysis Lab," *BentoBio*. https://www.bento.bio/bento-lab/. July 29, 2018.
[177] "Genetic Engineering Home Lab Kit," *The ODIN*, http://www.the-odin.com/genetic-engineering-home-lab-kit/. July 29, 2018.

and environmental woes. These include pollution and contamination issues, cheap water quality and environmental contamination detection technologies, and finding sustainable ways to produce biofuels and harnessing alternate sources of energy.

Summaries of Major U.S. Community Labs

Overview

This dissertation conducted on-site research at 9 community labs across the United States. A brief background of each community lab site is provided below from the existing literature, including when the lab was founded, leadership and membership composition when available, the types of projects done in these spaces, and capabilities if listed.

Baltimore UnderGround Science Space (BUGSS)

BUGSS is a community lab based in Baltimore, Maryland. Established in 2012, the community lab was built in a restored industrial brick building that used to manufacture gaskets and seals.[178] The main founder of BUGSS was Dr. Thomas (Tom) Burkett, a PhD in microbiology who taught biotechnology and biomanufacturing courses at the Community College of Baltimore. BUGSS was largely started through funds Tom

[178] "Baltimore Underground Science Space (BUGSS)," *Doors Open Baltimore*, 2021, https://www.doorsopenbaltimore.org/sites/baltimore-underground-science-space/. Accessed March 20, 2021.

and others personally provided to build the space.[179] Current funding models at BUGSS includes monthly membership fees that range from $25 - $100 per month.[180]

From its founding to the present day, BUGSS has operated as a non-profit organization, complete with a board of directors. One of these board members, Ed Wonilowicz, runs a biosafety consulting business. He has continued to offer Tom his advice and recommendations on the biosafety elements of BUGSS.[181]

BUGSS has activities that reflect all 4E's of DIYBio activity – education, entrepreneurship, exploration, and empowerment.[182] It hosts classes and seminars both virtually and on-site at the community lab, with topics ranging from microbiology, bio-art, and hands-on wetlab experience to the latest developments in biotech and COVID-19.[183] It also offers the lab space to budding entrepreneurs that want to try building biotech products or for developing proof-of-concept to demonstrate the feasibility of a proprietary method or protocol.[184]

The lab also houses 4 major group projects, which include 1) the Scramble and Synthetic Yeast project, an NSF-funded project to see how rearranging synthetic chromosomes in yeast can produce new yeast cells with interest properties; 2) the Barcoding the Inner Harbor Project, a project in collaboration with the National

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[179] For examples, see Scheifele and Burkett, "The First Three Years," 81; "About the Baltimore UnderGround Science Space," *BUGSS*, https://bugssonline.org/about/. Accessed March 21, 2021; and "Tom Burkett," *Global Community Bio Summit*, https://www.biosummit.org/tom-burkett. Accessed March 21, 2021.

[180] "Membership," *BUGSS*, https://bugssonline.org/membership/. Accessed March 21, 2021.

[181] "About BUGSS," *BUGSS*, https://bugssonline.org/about/. Accessed March 21, 2021.

[182] Scheifele and Burkett, "The First Three Years," 82.

[183] "Past Seminars," *BUGSS*, https://bugssonline.org/community/seminars/. Accessed March 21, 2021.

[184] "Entrepreneur Program," *BUGSS*, https://bugssonline.org/membership/entrepreneur/. Accessed March 21, 2021.

Aquarium and the Institute of Marine and Environmental Technology (IMET), which focuses on capturing and processing DNA samples, then identifying what organisms live in Baltimore's Inner Harbor on a genetic level; 3) the Baltimore Biocrew, which consists of high school students and BUGSS mentors participating in the synthetic biology event known as the International Genetically Engineered Machines (iGEM) competition; and 4) the Open Insulin Project, which seeks to create an open source model for insulin production to address the spiking insulin costs that pharmaceutical companies are currently charging – $40 monthly supplies of Novo Nordisk's insulin product NovoLog have risen to $289 in 2018, and other major pharmaceutical companies like Eli Lilly and Sanofi have seen similar and even greater increases.[185]

In terms of the community, BUGSS attracts a diverse audience. Depending on the class or seminar, the age range of participants can run from grade-school children accompanied by their parents to retired individuals looking for avenues to continue learning and expanding their horizons. Expertise can also widely vary at BUGSS. In terms of the life sciences, BUGSS members include PhD-level biologists at one end, and amateurs who have never held a pipette before on the other end. Members also bring

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[185] See "Scramble and Synthetic Yeast," *BUGSS*, https://bugssonline.org/group-projects/scramble-and-synthetic-yeast/. Accessed March 21, 2021; "Welcome to Barcoding the Harbor," *BUGSS,* https://bugssonline.org/group-projects/barcoding-the-harbor/. Accessed March 21, 2021; "The Open Insulin Project," *BUGSS*, https://bugssonline.org/group-projects/open-insulin/. Accessed March 21, 2021; "What is iGEM?,"*BUGSS,* https://bugssonline.org/igem-2/. Accessed March 21, 2021; and Ben Guarino, "Trump Boasted He Made Insulin So Cheap 'It's Like Water.' Americans with Diabetes Beg to Differ," *The Washington Post*, October 1, 2020, https://www.washingtonpost.com/health/2020/09/30/trump-insulin-cost/.

other perspectives and expertise that range from art and design and the humanities to technical experts in engineering and computer science.[186]

In terms of its lab space and capabilities, BUGSS is a Biosafety Level (BSL) 1 lab. It contains lab equipment that enable basic molecular and microbiology tasks and projects, such as running a gel electrophoresis, DNA isolation and purification, polymerase chain reactions to amplify DNA in samples, basic cellular genetic expression manipulation through transformations and genome editing in BSL-1 level-appropriate cells, and proper equipment to help incubate and store samples, as well as clean, disinfect, and sterilize used equipment.[187]

BioCurious

BioCurious is a community lab based in Sunnyvale, California. It holds the record of being the second community lab in the world. Established in 2011, the community lab started in a garage. Through a highly-successful Kickstarter campaign that raised over $30,000, the BioCurious founders were able to move from their garage lab to a 2500 square space in Silicon Valley that they converted into a larger, more functional lab.[188] Current funding models at BioCurious include a membership model where individuals

[186] Scheifele and Burkett, "The First Three Years," 81.
[187] "Lab Resources," *BUGSS*, https://bugssonline.org/lab-resources-2/. Accessed March 21, 2021.
[188] Eri Gentry, Joseph Jackson, and Tito Jankowski, "BioCurious: A Hackerspace for Biotech. The Community Lab for Citizen Science," *Kickstarter*, November 15, 2011, https://www.kickstarter.com/projects/openscience/biocurious-a-hackerspace-for-biotech-the-community. Accessed March 21, 2021.

and families can pay $150 - $200 per month, along with additional fees for dedicated storage space, use of the cell lines room, and other perks.[189]

The main founder of BioCurious was Eri Gentry, a graduate from Yale with a Bachelor's degree in Economics. She and 5 other founders, including biomedical engineer Tito Jankowski, personnel management professional Kristina Hathaway, computer scientist Josh Perfetto, bioinformaticist and biochemistry enthusiast Raymond McCauley, and political scientist Joseph Jackson built create and built BioCurious as a space with a complete laboratory and working space for citizen scientists, students, hobbyists, and entrepreneurs.[190] Currently, BioCurious operates as an official non-profit and has leadership in the form of a Board of Directors that sets the vision and addresses operational, safety, and logistical issues associated with the community lab.

BioCurious has activities that reflect all 4E's of DIYBio activity – education, entrepreneurship, exploration, and empowerment.[191] It hosts classes and seminars both virtually and on-site at the community lab, with topics ranging from micro- and molecular biology, biotech equipment demonstrations, and hands-on wetlab experience to the latest developments in biotechnology to hosting discussions about COVID-19.[192] Biocurious' close proximity to Silicon Valley also allows it to offer unique workshops for

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[189] "Biocurious FAQ: Membership," *BioCurious*, https://biocurious.org/faq/#membership. Accessed March 21, 2021.
[190] "About BioCurious" *BioCuriosity WordPress*, https://biocuriosity.wordpress.com/about/. Accessed March 21, 2021.
[191] "BioCurious FAQ: General," *BioCurious,* https://biocurious.org/faq/. Accessed March 21, 2021.
[192] Maria Chavez, Eric Espinosa, Ulrike, Anette, Innokenti Toulokhonov, and Patrik D'Haeseleer, "BioCurious Events," *MeetUp*, https://www.meetup.com/BioCurious/events/. Accessed March 21, 2021.

venture capitalists and biotech start-ups, as well as lab and office space for startups that want to build their proof of concept.[193]

The lab also houses 5 major group projects, which include 1) the Bioprinter project, where community members have come together for over 6 years to design an open source DIY cell printer; 2) the Cuttlefish Project which, starting in 2017, brought community members together to fully sequence the genome of a cuttlefish; 3) the Open Insulin Project, which seeks to engineer a protocol to develop insulin protein from engineered yeast cells as an open-source alternative to rising insulin costs from pharmaceutical companies; 4) the Real Vegan Cheese project, which looks to engineer yeast to produce casein-proteins as a vegan alternative to cow's cheese; and 5) the Kombucha Genomics project, which looks to isolate and identify bacterial and yeast strains from fermented foods such as kombucha.[194]

In terms of the community, Biocurious attracts a community that is simultaneously diverse and specific. Depending on the class or seminar, the age range of participants can run from grade-school children accompanied by their parents to retired individuals looking for avenues to continue learning and expanding their horizons. Expertise can also widely vary at BioCurious. In terms of the life sciences, BioCurious leaders and members include PhD-level biologists at one end, and amateurs who have never held a pipette before on the other end. While members also bring other perspectives and expertise that range from art and design and the humanities to technical experts in

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[193] See "BioCurious Workshops: Corporate Workshops BioCurious," *BioCurious*, https://biocurious.org/workshops/. Accessed March 21, 2021 and

[194] "BioCurious Projects: Active, Past, and Inactive Project List," *BioCurious*, https://biocurious.org/projects/. Accessed March 21, 2021;

engineering and computer science, the geographic location and nature of the lab (as a biotech incubator) tends to attract many engineers and biotechnologists.[195]

In terms of its lab space and capabilities, the majority of BioCurious is a Biosafety Level 1 lab. BioCurious also has a small room that is accessible to paying members for cell-line cultures – this room is designated a BSL-2 space. It also has a contains lab equipment that enable basic molecular and microbiology tasks and projects, such as running a gel electrophoresis, DNA isolation and purification, polymerase chain reactions to amplify DNA in samples, basic cellular genetic expression manipulation through transformations and genome editing in BSL-1 level-appropriate cells, and proper equipment to help incubate and store samples, as well as clean, disinfect, and sterilize used equipment.[196] In addition, it has some perks that not many other community labs have access to, including an on-site sequencer and lab-grade distilled water through a MilliQ water dispenser.

Biologik

Biologik is a community lab based in Norfolk, Virginia. The lab was founded and had a brick-and-mortar space starting in 2012. The founder, Jameson (Jamie) Dungan, identifies as a self-taught biohacker, which deviated significantly from his background in

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[195] See Cherise Fong, "Moving and Shaking DIY Biotech at BioCurious," *Makery*, October 16, 2018, https://www.makery.info/en/2018/10/16/english-moving-and-shaking-diy-biotech-at-biocurious/. Accessed March 21, 2021 and Lisa Krieger, "Biohackers Aim to Open Silicon Valley Lab for Group Research and Lessons, " *The Mercury News*, September 23, 2010, https://www.mercurynews.com/2010/09/23/biohackers-aim-to-open-silicon-valley-lab-for-group-research-and-lessons/. Accessed March 21, 2021.
[196] "Lab Resources," *BUGSS*, https://bugssonline.org/lab-resources-2/. Accessed March 21, 2021.

the humanities. He currently works as an IT support specialist in the Norfolk school district.[197] From the beginning to the present, Biologik was funded largely through Jamie's personal funds with occasional class fees and donations from supportive members and through outreach in the Norfolk community.[198]

The organization structure from the existing literature indicates it is very loose. Jamie had a co-founder named Rhett Sanders in the 2012 period, as well as several key members during the same time. Decisions are predominantly made by Jamie as he is the founder and major funder of the organization.[199]

Biologik activities reflect 3 of the 4E's: education, exploration, and empowerment. There were no indications in the existing literature that Biologik had any activities related to entrepreneurship. This aligns with the general goals of Biologik that Jamie indicates by noting he wants "to create a space that cultivates enthusiasm, science literacy, and embrace the notion of citizen science with active, novel contributions to research to all of science".[200] In terms of classes and seminars, Biologik activities include educational and hands-on demonstrations like strawberry DNA extraction classes and generating pink, glowing bacteria through bacterial transformation techniques.[201] Beyond

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[197] "Jameson Dungan," *Global Community Bio Summit*, https://www.biosummit.org/participants/2019/jameson-dungan. Accessed March 21, 2021.
[198] See "Help Fund BioLogik Labs – A Community BioHackerspace and Open Science Lab," *Reddit*, 2015, https://www.reddit.com/r/science/duplicates/237fh7/help_fund_biologik_labs_a_community/. Accessed March 21; and Jameson Dungan and Rhett Sanders, "A Community Biohacker Space and Education Center for Scientists of All Skill Levels and Ages," *Experiment.com*, May 10, 2014, https://experiment.com/projects/a-community-biohacker-space-and-education-center-for-scientists-of-all-skill-levels-and-ages. Accessed March 21, 2021.
[199] Ibid.
[200] Ibid.
[201] Jameson Dungan, "Strawberry DNA Extraction Classes and Pink Glowing Bacteria," *Experiment.com*, November 14, 2014, https://experiment.com/u/82SyzQ. Accessed March 21, 2021.

these classes and seminars, however, there is very little detail in the existing literature on any other activities this community lab does, as well as those that attend and operate in the space.

Finally, in terms of its lab space and capabilities, little is known. Using funds gathered through the crowd-sourcing platform Experiment.com, Biologik was able to open a functional lab geared towards the public in 2012. Their website indicates that BioLogik has the necessary tools and equipment to splice genes and make glow-in-the-dark bacteria, as well as having the knowledge, information, training, tools, and expertise necessary for amateur scientists and synthetic biologists.[202]

Biotech without Borders

Biotech without Borders is a community lab based in Brooklyn, New York. It was the second community lab founded by DIYBio visionary and molecular biologist Dr. Ellen Jorgensen – one of the original founders of the world's first community lab, Genspace. Established in 2017, its goal was to promote biotech practice and projects for useful and peaceful purposes dedicated to the benefit of humankind and the planet.[203] Funding for the lab space and its equipment predominantly came from Ellen and her connections through industry, as well as donations, class fees, $100 - $200 monthly membership fees, and donations through platforms like PayPal.[204]

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202 "What We Offer," *Biologik*, http://www.biologiklabs.org/?q=content/community-biohackerspace. Accessed March 21, 2021.
203 "Mission and History," *Biotech without Borders*, http://www.biotechwithoutborders.org/our-mission-and-history. Accessed March 21, 2021.
204 See "Donate with PayPal Giving Fund: Biotech without Borders, Inc.," *PayPal*, https://www.paypal.com/fundraiser/charity/2626844. Accessed March 21, 2021; "Bio Without Borders

Like most other community labs, Biotech without Borders is officially a non-profit organization. To fulfill part of the requirements of being a non-profit, Biotech without Borders is led by a board of directors, which is composed of three scientists: Dr. Ellen Jorgensen, Dr. Kumar Vadaparty, and Ms. Megan Walker. Board members create the vision and see to the administrative and logistic oversight of Biotech without Borders.[205]

Biotech without Borders hosts activities that reflect all 4 of the 4E's: education, exploration, empowerment, and entrepreneurship. Its classes range from teaching about the history of science and how to understand academic journals to hands-on classes and projects that teach everything from computer languages and synthetic biology to basic lab skills training.[206] While projects are not as visible to the public, their website indicates people interested in doing entrepreneurial projects can freely reach out to have their projects evaluated and potentially done at Biotech without Borders.[207] Biotech without Borders also interacts with high school students given that they have done iGEM projects in the past.[208]

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iGEM Team," *GoFundMe*, August 21, 2018, https://www.gofundme.com/f/igem-competition. Accessed March 21, 2021; "Classes," *Biotech without Borders*, http://www.biotechwithoutborders.org/classes. Accessed March 21, 2021; "Lab Memberships," *Biotech without Borders,* http://www.biotechwithoutborders.org/lab-memberships. Accessed March 21, 2021, and Biotech Without Borders, Twitter Post, January 24, 2020, 8:06 AM, https://twitter.com/BioWOborders/status/1220694295570735109?s=20. Accessed March 21, 2021.

[205] "Our Team," *Biotech without Borders*, http://www.biotechwithoutborders.org/our-team. Accessed March 21, 2021.

[206] "Classes," *Biotech without Borders*, http://www.biotechwithoutborders.org/classes. Accessed March 21, 2021.

[207] "Lab Membership," *Biotech without Borders.*

[208] "Congrats to the Brooklyn Bluebloods for their Bronze Medal at iGEM 2018!," *Biotech Without Borders*, http://www.biotechwithoutborders.org/igem-team. Accessed March 21, 2021.

While there is little in the existing literature on the composition of the Biotech without Borders community, there are some details available on its capabilities and its lab space. Biotech without Borders is one of the rare community labs that has both a BSL-1 and BSL-2 space in its organization. In the BSL-1 section, it contains lab equipment that enables basic molecular and microbiology tasks and projects, such as running a gel electrophoresis, DNA isolation and purification, polymerase chain reactions to amplify DNA in samples, basic cellular genetic expression manipulation through transformations and genome editing in BSL-1 level-appropriate cells, and proper equipment to help incubate and store samples, as well as clean, disinfect, and sterilize used equipment. Access and working to the BSL-2 section of lab requires training from lab leadership, but allows people with access to run tissue culture and cell-line work.[209]

BosLab

BosLab is a community lab that was originally based in Somerville, MA. It has since moved in 2019 to a location in Cambridge, MA, which it shares with another organization: the New England Friends of Bosnia and Herzegovina.[210] It was started and founded in 2015, and shared space with several other organizations in the same building with an underlying philosophy of giving back to the community. Its founders included biologist Dr. Angela Kaczmarczyk, microbial ecologist Dr. Mrina Nikrad, data scientist

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[209] "Lab Membership," *Biotech without Borders.*
[210] "About," *BosLab*, https://www.boslab.org/about. Accessed March 21, 2021.

Will Sutton, and several others – unfortunately, the existing literature on the history of BosLab is not well-documented.[211]

Funding and how BosLab got started are also unclear. However, it also operates as a non-profit organization and has a board of directors that shapes the lab's activities and addresses logistical and administration issues.[212] Part of BosLab's funding mechanism is through $50 monthly membership fees for those that desire full access to run projects and tasks in their lab, as well as fees for classes.[213]

In terms of its activities, BosLab hosts activities that reflect 3 of the 4E's: education, exploration, and empowerment. Its classes and seminars range from open houses, lectures, and discussion groups on the life sciences to actual hands-on courses on learning lab skills and the basics of biohacking.[214] Projects in this community lab are also diverse, ranging from finding ways to engineer yeast strains to change the characteristics of beer, sequencing backyard microbiomes, and making educational videos to teach people the basics of biology and biotech.[215]

In terms of BosLab's capabilities and lab space, it operates as a BSL-1 space. It contains lab equipment that enables basic molecular and microbiology tasks and projects, such as running a gel electrophoresis, DNA isolation and purification, polymerase chain reactions to amplify DNA in samples, basic cellular genetic expression manipulation through transformations and genome editing in BSL-1 level-appropriate cells, and proper

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[211] Angela Abitua, "Cultivating Community Science at BosLab," *AddGene*, November 2, 2017, https://blog.addgene.org/cultivating-community-science-at-boslab. Accessed March 21, 2021.
[212] "About," *BosLab*, https://www.boslab.org/about. Accessed March 21, 2021.
[213] "Participate," *BosLab*, https://www.boslab.org/participate. Accessed March 21, 2021.
[214] "What We Do," *BosLab*, https://www.boslab.org/. Accessed March 21, 2021.
[215] "Projects," *BosLab*, https://www.boslab.org/projects. Accessed March 21, 2021.

equipment to help incubate and store samples, as well as clean, disinfect, and sterilize used equipment.[216]

Counter Culture Labs

Counter Culture Labs (CCL) is a famous community lab based in Oakland, California. It was initially founded in 2013 by several individuals, including biotech business expert Ryan Bethencourt, biologist Mary Ward, and a bioinformaticist Dr. Patrik D'haeseleer.[217] The explicit goal of the lab is to democratize biotechnology and let all of humanity invent, innovate, and be a part of the age of biology.[218]

This lab initially was a garage lab. In 2014, members moved into the community center known as the Omni Commons: a space with nine other collectives that focus on pooling resources and collaborating towards social change.[219] This lab got its start by raising funds through an extraordinarily successful Kickstarter campaign that amassed more than $33,000. The founders used this funding to cover upgrades for plumbing, electric, ventilation and heat, getting a fume hood and other lab equipment, rent, and registering a team for the iGEM competition.[220]

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[216] "The Lab," *BosLab*, https://www.boslab.org/the-lab. Accessed March 21, 2021.
[217] See Samuel Jay Calvo, "Mary Ward | Co-Founder | Counter Culture Labs," *Medium*, June 2, 2016, https://medium.com/bio-science-magazine/mary-ward-co-founder-counter-culture-labs-b9412e4555da. Accessed March 21, 2021. "Ryan Bethencourt," *LinkedIn*, https://www.linkedin.com/in/bethencourt/. Accessed March 21, 2021; and "Patrik D'haeseleer," *LinkedIn*, https://www.linkedin.com/in/patrikdhaeseleer/. Accessed March 21, 2021.
[218] "About Us," *Counter Culture Labs*, https://www.counterculturelabs.org/info--history.html. Accessed March 21, 2021.
[219] Counter Culture Labs, "Counter Culture Labs – YOUR Biohacking & Citizen Science Lab," *Kickstarter*, May 27, 2015, https://www.kickstarter.com/projects/1836537355/counter-culture-labs-your-biohacking-and-citizen-s. Accessed March 21, 2021.
[220] Ibid.

Like most community labs, it also is a non-profit organization and has a board of directors to run the day-to-day activities, as well as administrative, logistical, and vision components of running the organization. Beyond the Kickstarter funding, CCL supplements its income through online donations, sponsorships, and membership fees, which range from $80 a month to memberships subsidized by the organization. This is the only community lab that actively promotes this type of membership, but this also aligns with the values of CCL in providing access to anyone and attempting to effect social change through biology.[221]

In terms of its activities, CCL seems to reflect all 4 of the 4E's. Its events vary wildly, but often include elements of teaching amateurs or exposing amateurs to new things, such as understanding how to interpret synthetic biology academic articles, creating a space to get the latest on COVID-19, and engage in bioart projects. They also host open houses and biohacker socials to help create a comfortable space for newcomers. In addition, they engage in 5 main projects, including 1) a Mushroom Meetup to study and cultivate mycoflora; 2) a Plant Biology group that studies and applies plants for research; 3) a Vegan Cheese project looking to engineer yeast to produce milk proteins; 4) the ArtSci project, which looks to create interesting products at the intersection of science, math, art, and engineering; and 5) the Open Insulin project, where participants are attempting to engineer east to product insulin protein as an alternative to the high cost of insulin from pharmaceutical companies.[222]

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[221] "Join Counter Culture!," *Counter Culture Labs*, https://www.counterculturelabs.org/join.html. Accessed March 21, 2021.
[222] "Projects," *Counter Culture Labs*, https://www.counterculturelabs.org/projects.html. Accessed March 21, 2021.

There is no extant literature that points to the demographics and who tends to join CCL. In terms of its lap space and capabilities, the main lab space is at a BSL-1 operational capability. Like many of the other community labs discussed, it houses similar equipment to run basic micro- and molecular biology experiments, such as running a gel electrophoresis, DNA isolation and purification, polymerase chain reactions to amplify DNA in samples, basic cellular genetic expression manipulation through transformations and genome editing in BSL-1 level-appropriate cells, and proper equipment to help incubate and store samples, as well as clean, disinfect, and sterilize used equipment.[223] In addition, CCL has a small room dedicated to mushroom cultivation, which typically is associated with the mycology event hosted at CCL every other week.[224]

Genspace

Genspace is officially considered the world's first community lab. Formed in 2009 and founded with a fully equipped laboratory space in 2010, it is a non-profit organization based in Brooklyn, New York.[225] Its original founders included biologist Dr. Ellen Jorgensen, science writer and journalist Daniel Grushkin, artist Nurit Bar-Shai, and biologist Dr. Oliver Medvedik. This group came together through the DIYbio Google Group and, all realizing that they wanted to work to make science accessible and fun for

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[223] "Equipment," *Counter Culture Labs,* https://www.counterculturelabs.org/equipment.html. Accessed March 21, 2021.
[224] Cherise Fong, "Counter Culture Labs, Cradle of Bay Area Biohacking," *Makery*, March 20, 2018, https://www.makery.info/en/2018/03/20/visite-aux-counter-culture-labs-berceau-du-biohack-californien/. Accessed March 21, 2021.
[225] "Home," *Genspace*, https://www.genspace.org/. Accessed March 21, 2021.

everyone to engage in, decided to open a community lab in 2010.[226] Since its opening in 2010, it has moved from its original space to a new space in Sunset Park, Brooklyn, in 2017.[227]

Like many of these non-profit organizations, Genspace has a board of directors. The board of directors come from diverse backgrounds, ranging from the arts and sciences to leaders in the maker movement and relationship managers with private donor foundations.[228] The directors take part in handling the priorities and vision of what type of organization Genspace is. Unusual for community labs, Genspace has sufficient funding to have paid staff fulfill day-to-day administrative, executive, and logistical functions. These roles include a Director of Operations, a Director of Science Education, a Program Associate, and a Manager for Development and Communications. The people that occupy these positions also have diverse backgrounds, ranging from art and design to science communication and molecular and biochemical nutrition.[229]

Public Genspace documents provide a clear image of funding streams for the organization. In its 2019 report, it had a total revenue of $501,054.50. This revenue was generated through five methods, including 1) Classes and workshops, which accounted for 24.3%; 2) Membership dues, which accounted for 11.3%; 3) Individual contribution, which accounted for 3.3%; 4) Foundation grants, which accounted for 59.9%; and 5) Other means, which accounted for 1.3%. Membership fees are tiered at Genspace, where $100/month buys someone a Community Membership to participate in community

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[226] Sam Kean, "A Lab of Their Own," *Science* 333, no. 6047 (2011): 1240 – 1241.
[227] "About the Lab," *Genspace*, https://www.genspace.org/the-lab. Accessed March 21, 2021.
[228] "AbdelHameid et al., "Genspace 2019 Annual Report," 44.
[229] Ibid., 44.

projects, $200/month buys someone an Individual Membership to run your own research in the lab, and $800/month buys someone a Premium Membership to run their own research in the lab and have dedicated desk space for administrative work.[230]

In terms of its activities, Genspace reflects all 4 of the 4E's. Its classes and events focus on everything from discussing and learning at the intersection of society, art, and biology to hosting hands-on classes where people can learn basic wetlab techniques, build their own equipment to fulfill desired functions, and learn to code in different computer languages like Python.[231] Genspace also has 4 main community lab projects it advertises, including 1) the Open Plant Collaboration, which focuses on understanding and eventually engineering liverwort cultures to perform synthetic biology experiments; 2) the Optogenetics Project, where members are learning to construct optogenetic systems (genetic tools that make cells responsive to light); 3) the Biomaterials and Design Project, where members attempt to approach biology from a design perspective with the goal making more sustainable materials and using eco-friendly manufacturing techniques; and 4) the Gadgeteering Community Project, which seeks to design and create open-source lab tools and gear for life sciences research and creative projects.[232] Given its Premium Membership geared towards businesses, it is clear that Genspace also is a space for entrepreneurship.

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[230] "Join the Lab," *Genspace*, https://www.genspace.org/join-the-lab. Accessed March 21, 2021.
[231] See "Classes," *Genspace*, https://www.genspace.org/classes. Accessed March 21, 2021 and "Events," *Genspace*, https://www.genspace.org/events. Accessed March 21, 2021.
[232] See "Events," *Genspace*; and "Community Projects," *Genspace*, https://www.genspace.org/community-projects. Accessed March 21, 2021.

There is no extant literature on the demographic diversity of Genspace. What the literature does state is that Genspace is a space where diverse disciplines interact, particularly from areas like engineering, fashion, art, design, and biology.[233] This unique community has led to collaborations between Genspace and organizations like the Fashion Institute of Technology, the New York Public School system, and even local companies.[234]

In terms of its lab space and capabilities, Genspace operates a BSL-1 lab and follows the appropriate guidelines for that designation. The community lab houses the equipment necessary to run basic micro- and molecular biology experiments, such as running a gel electrophoresis, DNA isolation and purification, polymerase chain reactions to amplify DNA in samples, basic cellular genetic expression manipulation through transformations and genome editing in BSL-1 level-appropriate cells, and proper equipment to help incubate and store samples, as well as clean, disinfect, and sterilize used equipment.[235]

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[233] For examples, see Sam Kean, "A Lab of Their Own,": 1240; Gabriela A. Sanchez Barba, "We Are Biohackers: Exploring the Collective Identity of the DIYBIO Movement," *Delft University of Technology*, August, 2014, https://www.researchgate.net/profile/Gabriela-Sanchez-5/publication/284727537_We_are_Biohackers_Exploring_the_Collective_Identity_of_the_DIYbio_Movement/links/565845c808aefe619b20e07f/We-are-Biohackers-Exploring-the-Collective-Identity-of-the-DIYbio-Movement.pdf. Accessed March 21, 2021; and Stacey Kuznetsov, Cassandra Barrett, Piyum Fernando, and Kat Fowler, "Antibiotic-Responsive Bioart: Exploring DIYbio as a Design Studio Practice." In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, No. 463 (2018), 1 – 14.

[234] See "High School Programs," *Genspace*, https://www.genspace.org/high-school-students. Accessed March 21, 2021; "Bring Your Office to the Lab," *Genspace,* https://www.genspace.org/corporate. Accessed March 21, 2021; and "Higher Education," *Genspace*, https://www.genspace.org/higher-ed. Accessed March 21, 2021.

[235] "About the Lab," *Genspace*, https://www.genspace.org/the-lab. Accessed March 21, 2021.

Indie Lab

Indie Lab is a small community lab based in Richmond, Virginia. It was initially founded by three individuals - It started out in early 2014 as a part of the HackRVA makerspace – a nonprofit space filled with tools, computers, and people who like to tinker, build, invent, learn, and share new skills.[236] It eventually moved from HackRVA to a shed located on the property of one of the co-founders in 2015.[237] Indie Lab was founded by three individuals, including biomedical engineer Elliot Roth, physicist Grace Cummings, and analytical chemist Dr. Bill Slavin.[238]

Indie Lab is also a non-profit company and, thus, has a board that runs its day-to-day operations, as well as setting its future trajectory and vision for what the space is for. This board includes a diverse group of biologists, computer scientists, technologists, and even family members of people associated with the community lab.[239]

There is little in the existing literature on how Indie Lab operates and gets its funding. When they occupied space at HackRVA, they paid rent to have a small, dedicated space for their lab.[240] Once they moved the space out of HackRVA onto Bill's residential shed, the cost for renting a space disappeared. Indie Lab has crowdsourced in the past – there is record of an unsuccessful GoFundMe Charity crowdsourcing effort for

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[236] See Aaron Nipper, "Indie Lab RVA in Action," *HackRVA Makerspace*, December 28, 2014, https://www.hackrva.org/2014/12/indie-lab-rva-in-action/. Accessed March 21, 2021 and "About," *HackRVA Makerspace*, https://www.hackrva.org/. Accessed March 21, 2021.
[237] "Indie Lab," *OpenEI*, https://openei.org/wiki/Indie_Lab. Accessed March 21, 2021.
[238] Taylor Thornberg, "Indie Lab RVA: Experimental Space," *The Commonwealth Times*, March 23, 2015, https://commonwealthtimes.org/2015/03/23/indie-lab-rva-experimental-space/. Accessed March 21, 2021.
[239] "Leadership," *Indie Lab*, http://www.indielab.co/leadership. Accessed March 21, 2021.
[240] Thornberg, "Indie Lab RVA".

$30,000 for Indie Lab to expand its COVID-19 testing apparatus to increase sample processing capacity in Richmond.[241]

It is difficult to gauge Indie Lab on how its activities reflect the 4E's as there is almost no documentation on its past activities. That said, there are examples where Indie Lab reflects 3 of the 4E's: education, exploration, and empowerment. Past events that Indie Lab has hosted included creating water bottle rocket demonstrations, classes on electroplating, and events on DNA extraction.[242] Indie Lab has also sought to create cheap and effective alternatives to masks, enhance COVID-19 testing capabilities, and find ways to replenish oxygen supplies for ventilators.[243]

In terms of its lab space and capabilities, Indie Lab is not explicit on what BSL it operates at. Given its equipment listing, it is likely that the biological projects that it runs are at a BSL-1 level, which allows the space to run basic micro- and molecular biology experiments, such as running a gel electrophoresis, DNA isolation and purification, polymerase chain reactions to amplify DNA in samples, basic cellular genetic expression manipulation through transformations and genome editing in BSL-1 level-appropriate cells, and proper equipment to help incubate and store samples, as well as clean, disinfect, and sterilize used equipment.[244] This space is unique given that it also houses

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[241] "Community Testing for COVID-19," *GoFundMe Charity*, March 17, 2020, https://charity.gofundme.com/o/en/campaign/community-testing-for-covid-19. Accessed March 21, 2021.
[242] Nipper, "Indie Lab RVA in Action".
[243] Jakob Cordes, "Richmond Research Lab Joins COVID-19 Fight," *Virginia Public Media*, April 22, 2020, https://vpm.org/news/articles/12756/richmond-research-lab-joins-covid-19-fight.
[244] "Resources," *Indie Lab*, http://www.indielab.co/resources. Accessed March 21, 2021.

equipment to allow activities outside of biology including chemical synthesis and extraction, as well as physics and engineering projects.[245]

Open Bio Labs

Open Bio Labs is a community lab based in the downtown area of Charlottesville, VA. It was founded in 2016 by Shaun Moshasha, whose background includes biochemistry, physics, and marketing. He eventually brought on additional personnel to help run and manage the three different programs that Open Bio Labs was meant to offer, including 1) the Learn program, which focused on providing K-12 students access to and hands-on experience with wetlabs and emerging biotechnologies; 2) the Build program, which is an open laboratory experience where people can pay to work on projects and use lab resources; and 3) the Grow program, where participants can work with Open Bio Labs leadership and develop their ideas to potentially grow companies, publish papers, and other goals.[246]

Little information exists on the organizational structure of Open Bio Labs, although it should have a board given it is recognized formally as a nonprofit organization.[247] Shaun functions as an instructor and the founder of the community lab. In addition, Dr. Charles Richardson, a molecular biologist, functions as the Director of

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245 Ibid.

246 See "About," *Open Bio Labs*, https://openbiolabs.org/about/. Accessed March 21, 2021; "Grow," *Open Bio Labs,* http://openbiolabs.org/grow/. Accessed March 21, 2021; "Learn," *Open Bio Labs*, http://openbiolabs.org/learn/. Accessed March 21, 2021; and "Build," *Open Bio Labs*, http://openbiolabs.org/build/. Accessed March 21, 2021.

247 "Work with Us," *Open Bio Labs,* https://openbiolabs.org/work-with-us/. Accessed March 22, 2021.

Education, microbiologist Dr. Billy Nash is the Director of the Grow Program, and entrepreneur Rob Masri holds the title of Board of Directors.[248]

From the existing literature, Open Bio Labs gathers funding for its space and activities through three means. First, it accepts donations through its online website as well as crowdsourcing funds for projects the space is running.[249] Second, it has a membership scheme where participants can pay $100/month to work and do projects in the lab.[250] Finally, Open Bio Labs offers multi-lesson courses through an instructor at the lab for set prices.[251]

Open Bio Labs' activities reflect all 4E's associated with DIYBio. Its three program branches of Build, Learn, and Grow all contain activity elements of teaching science for educational purposes to K-12 students, encouraging people to try learning about science through lectures and hands-on experience, as well as giving people the space and equipment necessary to run their own projects in the space.[252] In terms of entrepreneurial ventures beyond just the Grow Program, there was reference of a local Charlottesville startup venture called Cerillo that used the community lab to develop novel laboratory equipment.[253]

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248 "About," *Open Bio Labs.*

249 See "Using Spirulina for Carbon Capture," *Experiment.com*, January 11, 2019, https://experiment.com/projects/removal-of-carbon-dioxide-from-the-atmosphere-via-the-respiratory-metabolism-of-spirulina. Accessed March 21, 2021 and "Work with Us," *Open Bio Labs*, https://openbiolabs.org/work-with-us/. Accessed March 22, 2021.

250 "Our Lab," *Open Bio Labs*.

251 "Courses," *Open Bio Labs*, http://openbiolabs.org/courses-3/. Accessed March 21, 2021.

252 "About," *Open Bio Labs*.

253 Josh Mandell, "Open Bio Labs Hosts Conference for Community-Based Science," *Charlottesville Tomorrow*, July 30, 2017, https://www.cvilletomorrow.org/articles/open-bio-labs-hosts-conference-for-community-based. Accessed March 21, 2021.

In terms of its lab space and capabilities, the lab listing on Open Bio Labs indicates that it is able to do basic micro- and molecular biology tasks and projects, such as running a gel electrophoresis, DNA isolation and purification, polymerase chain reactions to amplify DNA in samples, basic cellular genetic expression manipulation through transformations and genome editing in BSL-1 level-appropriate cells, and proper equipment to help incubate and store samples, as well as clean, disinfect, and sterilize used equipment.[254] There is no indication in the existing literature of what BSL it operates at.

Methods

This dissertation had two main goals. The first goal was to gather information on the U.S. DIYBio community that related to the 3Ds. This was accomplished through gathering two main qualitative data sources throughout the dissertation field research period: April 2019 – March 2020. The first type was observation data acquired while doing on-site visits of community labs during this research timeframe. The second type was interview data done through recorded video chats with community lab members and leaders associate with the labs I physically observed.

The second goal was to apply the findings of the 3Ds to assess how the DIYBio community labs I observed and engaged with were changing the biorisk threat landscape in the United States. To do this, I used the qualitative data analysis software NVivo to collate, code, and analyze the observation and interview data sets for insights and themes

[254] "Our Lab," *Open Bio Labs*.

of interest concerning the 3Ds. These themes and interests concerning the 3Ds were then compared to expectations distilled from the terrorism and STS literatures to produce a current biorisk threat assessment of DIYBio community labs.

#1 - Choosing and Gaining Access to Sites

To fulfill the first goal, I began by examining the state of the DIYBio community since 2013 to identify sites to focus on. This research was guided by the 2013 Wilson Center study and a widely used DIYBio website and forum known as DIYBiosphere. Through this research, I discovered that out of the 42 U.S. DIYBio labs and start-ups listed in DIYBiosphere as active, 35 were in urban areas that were either close to higher education institutes or high-tech centers. In addition, nearly half of all these existing U.S. DIYBio community laboratory spaces were in four geographic regions: California, the Metropolitan DC area, Massachusetts, and New York. I then combined these discoveries with a central finding from the 2013 Wilson Center report: 90% of biohackers throughout the world work in community labs.[255]

From this research, I decided to focus on biohackers, citizen scientists, amateur biologists, and other practitioners of the life sciences that operate in 9 community labs in the United States in California, the Metropolitan DC are, Massachusetts, and New York. Prior to my arrival at each of these 9 community labs, I contacted the leadership of each community lab, discussed the purpose and the proposed methods of my research with

[255] Grushkin, Kuiken, and Millet, "Seven Myths and Realities,", Wilson Center, 2013, https://www.wilsoncenter.org/publication/seven-myths-and-realities-about-do-it-yourself-biology-0.

each lab's governing board or decision-making leader, and sought permission to conduct research in these spaces. I was granted permission by all the labs I contacted and ended up conducting my research at the labs listed in Table 1.

Table 1 – DIYBio Community Lab Sites and Observation Data Distribution

Number (#)	Community Lab Name	Community Lab City	Community Lab State	Number of Events Observed	Number of Visits (Total)
#1	BUGSS	Baltimore	Maryland	52	34
#2	BioCurious	Santa Clara	California	3	3
#3	Biologik	Norfolk	Virginia	0*	0*
#4	Biotech without Borders	Brooklyn	New York	5	3
#5	BosLab	Cambridge	Massachusetts	8	4
#6	Counter Culture Labs (CCL)	Oakland	California	10	6
#7	Genspace	Brooklyn	New York	4	3
#8	Indie Lab	Richmond	Virginia	1**	1**
#9	Open Bio Labs	Charlottesville	Virginia	1**	1**

Note – In this table, single * indicates that no site visit could be conducted at the community lab due to the COVID-19 pandemic, while a ** indicates a site visit had occurred, but additional site visits could not be conducted due to the COVID-19 pandemic.

#2a - Observation Data in Field Research

To gain insight on the 3Ds across the 9 community labs studied in this dissertation, I gathered two different sets of qualitative data. The first set of data that I gathered was what I observed while physically on-site during events at each of the community labs between April 2019 through March 2020. Observations during these on-site visits fell into two categories, including 1) passive participation, where I would make observations without interacting with the participants; and 2) active participation, where I fully engaged community lab members and participated in activities like learning lab skills, teaching students, and running experiments with other community lab members.

This observation data was captured through a combination of a hand-written field note diary, as well as photographs and video taken with my personal cell phone. This data was then logged in greater detail than in the abbreviated field note diary within 24- 48 hours of the initial observations in Word documents, with one document accounting for one event.

Transportation and accommodations were funded by a generous dissertation completion grant by George Mason University's Schar School. In total, I gathered observation data for 84 events across 55 on-site visits at 8 community labs (see Table 1). These events fell into five categories, including 1) Lab skill classes, where instructors at the community lab taught specific wetlab skills to the community; 2) Seminars and lectures, where experts would be invited to talk about a topic of interest to the community; 3) Public engagement events, where community lab leadership and members would raise awareness of their organization through community outreach and open house events; 4) Project events, where community lab members would research, develop, and engage in community science projects; and 5) Social events, where community lab members would have meals, discuss their personal lives, and engage in camaraderie.

Unfortunately, due to the COVID-19 pandemic, I was unable to do gather any on-site observation data at Biologik – a community lab based in Norfolk, Virginia. Further, due to the COVID-19 pandemic, I was only able to gather on-site observation data at Indie Lab and Open Bio Labs for one event at each lab.

#2b - Interview Data

In addition to observation data, I also used the opportunity presented by on-site interactions to find community lab members and leaders that would consent to an interview. I directly contacted community lab members and leaders who had expressed interest and offered consent to be interviewed for the purposes of this dissertation via e-mail. All these prospective interviewees then formalized their consent per the protocols approved by George Mason University's Institutional Review Board (IRB).

The one exception to this was the case of Biologik, as I was unable to physically get to Norfolk during the dissertation research timeline due to COVID-19. In the case of Biologik, I was able to find and schedule interviews through my existing relationship with the founder of the community lab. These prospective interviewees also formalized their consent to an interview per the protocols approved by George Mason University's IRB.

I conducted individual interviews for a total of 43 community lab members and leaders across the 9 community labs. Of these 43 individual interviews, 8 interviews were conducted with community lab founders, 18 interviews were conducted with community lab leaders and 18 interviews were conducted with community lab members. While this total of 44 interviews may seem like an error compared to 43 individual interviews, the discrepancy of the interview number is due to Dr. Ellen Jorgensen, who was interviewed for a single session but provided insight as the founder of two community labs: Genspace and Biotech without Borders. Table 2 provides additional detail on the distribution of interviewees.

Table 2 – DIYBio Community Lab Sites and Interview Distribution

Number (#)	Community Lab Name	# of Members Interviewed	# of Leadership Interviewed	# of Founders Interviewed	Total # of Individuals Interviewed
#1	BUGSS	4	4	1	9
#2	BioCurious	2	2	0	4
#3	Biologik	1	0	1	2
#4	Biotech without Borders	2	1	1	4
#5	BosLab	4	6	0	10
#6	Counter Culture Labs (CCL)	5	2	1	8
#7	Genspace	0	2	2	4
#8	Indie Lab	0	0	1	1
#9	Open Bio Labs	0	1	1	2

I conducted and recorded all the interviews through the Microsoft video communication platform Skype to both maximize my time to observe individuals and events during my site visits, as well as increase the success of scheduling interested interviewees. This method of interview proved to be effective throughout the dissertation research process. It also proved to be the only way I could conduct 26 out of my 43 total interviews, which took place from March 2020 through April 2020, following the emergence of the COVID-19 pandemic.

The virtual nature of the interviews made it easy to hold interviews across geographic distances and provided a simple way to record audio and video data for research purposes. However, there were 2 main limitations to the Skype approach that I experienced throughout the dissertation research process. The first was unpredictable video and audio quality issues – it was common for the video calls to freeze at times or audio quality to degrade unexpectedly, which resulted in delays and interruptions in the flow of the interview. Second, virtually scheduled appointments are easier to miss than in-person schedule appointments, resulting in several times where I had to reschedule interviews.

These interviews were in a semi-structured style to maximize consistency across the all the interviewees while simultaneously allowing some flexibility to explore spontaneous topics of interest that may unexpectedly arise during the interview process. The structure of the interview involved the same basic questions across all participants. These questions included 1) a brief introduction of the participant; 2) how they found out about DIYBio and the community lab they were affiliated with; 3) what attracted them to both start and continue participating; 4) what they saw as the values and ideologies of their community lab; 5) the types of activities that their community lab engaged in; 6) the types of projects their community lab would do; 7) the types of projects and tasks other community labs were undertaking if expressed they had previous interactions with other spaces; 8) the organizational structure and funding mechanisms of their lab; 9) their unique experiences in the space that they believed either helped or hindered accomplishing scientific tasks; and 10) their unique experiences in the space that would shed light on factors that expand or limit community lab capabilities.

In the case of community lab of community lab founders, I asked two additional questions beyond the typical interview script. The first was on what inspired them to build a community lab. The second was to have the founders reflect on their personal experiences to uncover factors that helped or hindered the founding of their community lab.

Following the completion of the interview, I transcribed the entire dialogue of the interview in a Word document, resulting in 43 separate Word documents. For interviewees that requested a copy of the interview transcript for review or for their personal record, I provided a complete copy of the transcript within 72 hours following the completion of the interview. For the 3 interviewees that requested the interview transcript to make sure their words and meaning were reflected accurately, I received no follow-up response requesting that changes needed to be made to the transcript.

#3 - Data Compilation and Coding through NVivo

I used the software program NVivo (version 12.0 for Windows) to collate, sort, characterize, code, and analyze the observation and interview data acquired through the dissertation research process. To collate the data, I created a new project within the NVivo software and imported the observation and interview files directly into the program, resulting in a total dataset of 131 files for analysis – 88 Word documents detailing observations from field data (on-site events and interactions in-person with community labs) and 43 Word documents that were complete transcripts of 43 individual interviews I conducted with community lab members, leaders, and founders across the 9 community labs in this study. These files were then characterized as two different sources of data, field data and interviews.

I then began the process of reading and reviewing the data to begin the coding process. Coding is a key step in preparing raw data for analysis. It requires the researcher to go over every piece of data available and categorize segments of data that appears significant or thematic with a code: a word or phrase that both summarizes and accounts for each piece of important data in a data set. Coding is a necessary step as it allows the researcher to transform raw data with data that has specific meanings, contexts, and purpose.[256]

Coding is a natural progression in the data analysis given this study took an ethnographic approach to gather qualitative data on DIYBio community labs through

[256] "Chapter 12: Making Meaning from Your Data," *Sage Publishing*, https://www.sagepub.com/sites/default/files/upm-binaries/45660_12.pdf. Accessed March 21, 2021.

observational and interview data. I used an iterative process totaling 3 complete cycles where I looked through and coded the data over the course of May 2020 – September 2020. This process helped refine my data to develop codes that not only had individual significance, but also generated categories and relationships between codes. Appendix A contains a complete list of codes that I uncovered through my data analysis.

#4 – DIYBio Biorisk Threat Assessment

Once data coding was completed, I used the data to analyze how U.S. DIYBio community labs are affecting the biorisk threat landscape. This dissertation focused on three biorisk narrative assumptions that needed to be addressed to better understand the change in biorisk threats that the U.S. DIYBio community may or may not pose. These 3 assumptions included how U.S. community labs 1) must be assumed to have malicious intent; 2) technical expertise and equipment is all that is required to successfully complete complex scientific tasks and projects; and 3) indicate that everyone can and does have access to all the equipment, materials, reagents, and information necessary to do biology.

To address the assumption that U.S. community labs must be treated as if they had malicious intent, I read through the bioterrorism literature and distilled two factors associated with heightened biorisk from non-state actor groups: a transformative ideology compared to the status quo and a desire to do violence. I then compared these factors to the drives of founders, leaders, and members of the U.S. DIYBio community labs I visited. This comparison concluded with an analysis of how the U.S. DIYBio community lab data either confirmed, denied, or contextualized these two factors, the implications of the findings, and limitations associated with the analysis.

To address the assumption that technical expertise and equipment are all that are necessary to perform complex scientific tasks and projects in the DIYBio community lab context, I read through the STS literature and distilled X traits associated with the successful completion of complex scientific tasks and projects, which include: 1) building and sharing tacit knowledge and expertise; 2) having an organizational structure that allows for the autonomy of the individual to perform necessary tasks and the ability to communicate freely with others; 3) an active manager that helps create a sense of community and trust, maintains transparency throughout the entire scientific process, and advocates for the program with outside stakeholders to provide adequate, stable funding and attention; 4) having a social environment that is conducive to building trust; and 5) having adequate and stable funding and material resources available to fund and push the project forward. I then compared these factors to the design factors of community labs, which included the type of expertise present in these spaces, how expertise was acquired and transferred, the role of leadership in community lab activities and projects, the social environment cultivated in these spaces, and the financial elements associated with these spaces. This comparison concluded with an analysis of how the U.S. DIYBio community lab data either confirmed, denied, or contextualized these 5 factors, the implications of the findings, and limitations associated with the analysis.

Finally, I addressed the third assumption - U.S. community labs mean that everyone can and does have access to all the equipment, materials, reagents, and information necessary to do complex life sciences tasks and projects. I read through the existing STS and Information Technology literatures to distill two factors that were associated with a greater degree of democratization: market accessibility (the degree to which a drive exists to increase the accessibility of equipment, materials, tools, reagents, and other goods associated with the life sciences) and information accessibility (the degree to which a drive exists to make information obtainable and collaboration possible across individuals and communities that fall outside traditional life sciences institutions like academia, industry, and government). I then compared these factors to the degree of democratization factors of community labs, including access to equipment and finances, and information sharing within and across community lab spaces. This comparison concluded with an analysis of how the U.S. DIYBio community lab data either confirmed, denied, or contextualized these factors, the implications of the findings, and limitations associated with the analysis.

CHAPTER FOUR – THE BIORISK IMPLICATIONS FOR THE DRIVES OF DIYBIO COMMUNITY LAB FOUNDERS AND MEMBERS

Introduction

Chapter 4 focuses on analyzing the biorisk narrative's assumption that DIYBio community labs can harbor malicious intent and should be treated as such. This chapter will begin by providing a brief overview of the existing bioterrorism literature to highlight two factors that indicate increased biorisk threats from non-state actors: an ideology that challenges the status quo and a desire for violence.

This chapter then provides a basic overview of founder drives, as well as initial and current drives for community lab members. The study finds that drives across all these categories fall under one of three categories: building and cultivating **community**, enabling **access to capabilities**, and **transformative change**. I then compared these drives and supporting data with the two factors that indicate increased biorisk threats.

I arrived at three main findings. First, one of the main drives of starting and operating in DIYBio community labs is to effect transformative change with how society interacts with biology – the result is an attempt to disrupt the status quo by spreading life sciences knowledge, equipment, materials, and reagents beyond the traditional institutions of academia, industry, and government. Second, while transformative change was one of the stronger drivers for why founders started community labs, it lags in comparison to the other two drivers for initial and current drives for members. Third, despite the desire to be disruptive and effect change contrary to the status quo, the data indicates that DIYBio community lab founders and members lack the desire to bring about change through violent means –the evidence points to how DIYBio community labs value pursuing their change through law-abiding and peaceful means.

Finally, this section concludes with the implications and limitations of these findings. On the one hand, the DIYBio community is seeking to disrupt the status quo by making the life sciences significantly more accessible to a broader participant pool, which is analogous to the drive that prospective bioterrorists have in terms of a desire to change the status quo. On the other hand, the data from this study indicates that the DIYBio community lacks a critical component of increasing the biorisk threat landscape: a desire to pursue change to the status quo through violent means. Therefore, despite limitations associated with sampling, and potential bias and observer effects, this analysis concludes that the biorisk assumption that U.S. DIYBio community labs should be treated as if they harbor malicious intent is erroneous and needs to be reconsidered.

The Biorisk Perspective – Malicious Intent Must Be Assumed for the DIYBio Community

Starting in the 1970's and onward, bioterrorism cases appeared to be trending upwards. Significant bioterrorist events such as the 1984 Rajneeshee attempt to swing a political election in their favor through the dispersal of *Salmonella typhimurium* at local salad bars and eateries, the various attempts of the Japanese millenarian cult Aum Shinrikyo to develop and use biological weapons in the 1980's through the 1990's, and the 2001 Amerithrax incident in a post-9/11 geopolitical environment raised the alarm for the biorisk community about a potential wave of global bioterrorism – a global bioterrorism driven in large part by increased access to information, cutting-edge equipment, and materials.[257]

The bioterrorism literature acknowledges that technical capabilities and access to information are not the only determinants of non-state actors choosing to pursue or use pathogens as weapons. A key component of whether non-state actors pursue biological weapons research and use is the motivations of the group. [258] The logic here is that biological weapons may not align with non-state actor outcomes by alienating supporters using a taboo weapon, exposing operations prematurely through a lab accident, or being too difficult given a lack of expertise within the group.[259]

The bioterrorism literature provides motivations that are associated with non-state actors and choosing to pursue biological weapons. According to WMD terrorism expert Jonathan Tucker, motivations can include religious, nationalist, and ecological motivations that drive terrorists to use any means to destroy their adversaries.[260] WMD terrorism expert Seth Carus expands further in his work on biocrimes and bioterrorism by

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[257] For examples, see Tucker, *Toxic Terror*: 249 – 269; W. Seth Carus, "RISE, the Rajneeshees, Aum Shinrikyo, and Bruce Ivins," in *Biological Threats in the 21st Century*, ed. Filippa Lentzos (New Jersey: Imperial College Press, 2016), 171 – 197; Jessica Stern, *Terror in the Name of God* (New York: Harper Collins Publishers, 2004), 185 – 186; Jonathan B. Tucker and Raymond A. Zilinskas, "The Promise and Perils of Synthetic Biology," *The New Atlantis*, no. 12 (2006), 25 – 45; John P. Caves, Jr. and W. Seth Carus, *The Future of Weapons of Mass Destruction: Their Nature and Role in 2030* (Washington DC: National Defense University Press, 2016): 21 – 28; Jessica Stern, "Terrorist Motivations and Unconventional Weapons," in *Planning the Unthinkable: How New Powers Will Use Nuclear, Biological, and Chemical Weapons*, eds. Peter R. Lavoy, Scott D. Sagan, and James J. Wirtz (Ithaca, NY: Cornell University Press, 2000), 202 – 229; Frank L. Smith III, *American Biodefense: How Dangerous Ideas About Biological Weapons Shape National Security* (Ithaca, NY: Cornell University Press), 108 – 120; Gregory D. Koblentz, "Pathogens as Weapons: The International Security Implications of Biological Warfare," *International Security* 28, no. 3 (2004), 84 – 122; and Vogel, "Framing Biosecurity", 45 – 48.
[258] Tucker, *Toxic Terror*: 9 – 12.
[259] For examples, see Stern, "Terrorist Motivations and Unconventional Weapons," in *Planning the Unthinkable*, eds. Lavoy et al. (2000), 202 – 205 and Catherine Jefferson, "Protein Engineering," in *Innovation, Dual Use, and Security*, ed. Jonathan Tucker (2012), 118 – 130.
[260] Ibid., 11.

noting that non-state actors that engage in bioterrorism use such weapons on behalf of a "political, religious, ecological, or other ideological cause".[261] Both of these experts overlap in that non-state actors motivated to research and pursue biological weapons are seeking to achieve some ideological goal that is disruptive to the status quo. This disruption includes preventing an undesired change, or to instigate a change desired by the non-state actor.

The second element to consider when it comes to DIYBio community labs in the U.S. and the bioterrorism literature is a more fundamental one. If the DIYBio community does have an ideology or approach to technology democratization that is disruptive to the status quo, does that necessarily mean that they will use violent means to fulfill their ideology? With violent non-state actors engaged in terrorist acts, the willingness to engage in violent acts is a given. While the case is less clear with U.S. DIYBio community labs, the biorisk narrative asserts this to be the case given its concerns of the community generated by the garage biology narrative and the anti-establishment and counterculture rhetoric the community uses to describe democratizing the life sciences.

Therefore, understanding two drivers is essential in determining whether U.S. DIYBiology community labs display the malicious motivation to pursue biological weapons. The first is an ideology that is disruptive to either the status quo or desired change by the majority. The second driver to study is a propensity for destruction or violence – the willingness of a group to use violent means to accomplish their ideological goals.

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[261] Carus, "Bioterrorism and Biocrimes,": 3 – 4.

The Drives of U.S. DIYBio Community Lab Participants

Overview

I predominantly received information on the drives of community lab participants through interview data as each interview contained questions about the initial and current motivations for why interviewees continued to participate in a community lab. Given their unique role in building the DIYBio community lab network, founders and co-founders were asked additional questions on what motivated them to start their own lab.

To avoid confusion during the analysis, all interviewees could only fall under one category of participation: participant, leader, or founder. The real world is more complex than this – for example, there are several occasions where community lab founders continue to occupy leadership roles in these spaces. However, this delineation helps remove potential bias by providing a clear line between those that founded the organization, and the leaders and members who came onboard at a later period.

In total, there were 8 founders or co-founders of community labs who were interviewed in this study, along with 18 leaders and 18 participants. For the purposes of this dissertation, I aggregated the leaders and participants groups into a category called members to make the biorisk threat evaluation more straight-forward. Zeroes indicate that I was unable to interview anyone in that lab associated with that category of participant during my dissertation research period. This issue happened predominantly in Indie Lab, Biologik, and Open Bio Labs: three community labs that I was unable to visit fully due to the ongoing COVID-19 pandemic. In the case of both BosLab and BioCurious, I was unable to get an interview with any of the original founders due to a combination of scheduling issues and difficulty in tracking down reliable means of communication for these members, even with the help of the community labs I did field research at. Table 3 below shows the distribution of member, leader, and founder interviews across all 9 community labs in this study.

Table 3 – DIYBio Community Lab Sites and Interview Distribution

Number (#)	Community Lab Name	# of Members Interviewed	# of Leadership Interviewed	# of Founders Interviewed	Total # of Individuals Interviewed
#1	BUGSS	4	4	1	9
#2	BioCurious	2	2	0	4
#3	Biologik	1	0	1	2
#4	Biotech without Borders	2	1	1	4
#5	BosLab	4	6	0	10
#6	Counter Culture Labs (CCL)	5	2	1	8
#7	Genspace	0	2	2	4
#8	Indie Lab	0	0	1	1
#9	Open Bio Labs	0	1	1	2

Founder Drives

Overview

In total, 7 founder interviews and 4 observational field data notes contained 60 references on what drove U.S. DIYBio community lab founders to start and build community labs.[262] The coding analysis uncovered three categories of drives that led to community lab founders to start and build their own community lab: community, access to capability, and transformative change. Table 4 below provides a visual of the number of files and references associated with the categories that emerged from the coding analysis.

Table 4 – Founder Drive Categories with Associated # of Files and References

Drive Category	# of Interviews	# of Notes	# of References
Community	5	4	29
Transformative Change	6	1	22
Access to Capabilities	4	1	9

[262] This data set includes founder interviews with Dr. Thomas Burkett of BUGSS, January 31, 2020; Mr. Daniel Grushkin of Genspace, February 24, 2020; Mr. Jameson Dungan of Biologik, March 21, 2020; Mr. Shaun Moshasha of Open Bio Labs, March 22, 2020; Dr. Bill Slavin of Indie Lab, April 03, 2020; Dr. Ellen Jorgensen of Genspace and Biotech without Borders, April 22, 2020; and Dr. Patrik D'haeseleer of CCL, April 30, 2020. It also includes observational field data notes, including "Field Notes 007 – Conversation with Tom Burkett (1000 – 1230)," April 13, 2019; "Field Notes 009 – Introductory Visit Hosted by Indie Lab," April 25, 2019; "Field Notes 073 – Panel Talk," October 12, 2019; and "Field Notes 080 – Casual Impromptu Talk," February 10, 2020.

Founders Driver #1 - Community

Founders most often referenced that helping to create and build a science-loving **community** was what drove them to start a community lab. For individuals like BUGSS founder Tom Burkett, their connection to the DIYBio community was to be inspired by community lab start-ups like Genspace and BioCurious. For others like Biologik founder Jameson Dungan, he was inspired to start a community lab based on his personal experiences of having his interest in the life sciences sparked by iGEM and synthetic biology – he wanted to create Biologik as a space where even people without experience, but with a passion for science, could learn science knowledge and basic scientific techniques.[263] Finally, for founders like Dr. Ellen Jorgensen, she sought to build community labs to build bridges between seemingly distant communities like scientists and citizens – her inspirations for founding Genspace included having families do science experiments together, as well as having an unconventional space where scientists in casual clothes could talk to citizens and not talk down from the ivory tower.[264] Table 5 on the following page provides additional details on the distribution of references for each subcategory based on the community lab:

[263] Lim, "Interview 22 – Jameson Dungan," March 21, 2020.
[264] Ibid.

Table 5 – Community Driver Sub-Categories, Distribution Data and References Across Labs for Founders

Community Labs	Inspired by the DIYBio Community	Building Bridges between Scientists and Citizens	Building a Science Enthusiast Community
BUGSS	2	1	1
Biologik	2	3	0
Biotech without Borders	0	2	0
CCL	0	0	0
Genspace	2	4	4
Indie Lab	1	1	1
Open Bio Labs	1	1	1

Founders Drive #2 – Transformative Change

Founders also referenced how they were driven to start community labs due to a desire to bring about some form of transformative change to the life sciences landscape. Some founders, such as Jamie of Biologik and Ellen Jorgensen of Genspace and Biotech without Borders, felt that traditional science cultivated an air of opacity in the way it operated and was explained to the public. Both founders expressed frustration at how they felt citizens were both shut out of the scientific process and conditioned to believe that an inability to understand science meant that a person was stupid.[265] Jamie passionately expressed this view by noting how he wanted people to build a space as a space to demystify science:

[265] See Lim, "Interview 42 – Ellen Jorgensen," April 22, 2020; and "Interview 22 – Jameson Dungan," March 21, 2020.

"I just want to have that attitude and thought for a lot of kids that science isn't this intimidating thing that's outside of them, or beyond them, or they're too stupid to learn, or they don't have the skillset to do. It was something they did as a kid and they could get back into it at any moment if they wanted to."[266]

Other founders felt that community labs could serve as catalysts for addressing unmet needs. For some, like Genspace founder Dan Grushkin and CCL co-founder Patrik D'haeseleer, community labs offered an alternative for mid-career professionals that wanted to learn about science but did not want to start up a whole new degree in a 4-year academic institution.[267] For Tom, he found that the academic institution was not supportive of having non-student community members involved on their science teams for competitions like iGEM – he saw founding a community lab as a transformative solution to deal with this issue.[268] Genspace and Biotech without Borders Founder Ellen Jorgensen, along with Indie Lab founder Bill Slavin, saw academia failing its students by not providing students with the right opportunities and skills to succeed in studying the life sciences. Ellen recounted how 2 of her co-founders at Genspace had difficulty accessing labs in academia:

"Two were students – one from NYU and one from Columbia – who were undergrads who had aspirations to go to iGEM, but their schools weren't interested.

[266] Lim, Interview 22 – Jameson Dungan," March 21, 2020.
[267] See Lim, "Interview 17 – Daniel Grushkin," February 24, 2020 and Lim, "Interview 43 – Patrik D'Haeseleer", April 30, 2020.
[268] Lim, "Interview 13 – Tom Burkett," January 31, 2020.

And they couldn't find professors to let them into the lab to try out cool ideas that they had because, of course, everyone was, and still is, scrambling for funding."[269]

Table 6 below provides additional details on the distribution of references for each subcategory based on the community lab:

Table 6 – Transformative Change Drive Sub-Categories, Distribution Data & References Across Labs for Founders

Community Labs	Addressing Unmet Needs	Demystifying Science
BUGSS	3	0
Biologik	1	2
Biotech without Borders	2	1
CCL	3	0
Genspace	6	0
Indie Lab	2	0
Open Bio Labs	0	2

Founder Drives #3 – Access to Capabilities

The least referenced category of how founders were driven to start community labs was to increase accessibility to capabilities for the life sciences outside of academia, industry, and government. For CCL founder, the issue came down to two issues. First, he chose to start his own community lab because getting to BioCurious was a logistical challenge.[270] He also expressed how community labs enable people to both learn from and teach others new skills through peer to peer interactions based on what expertise people in

[269] Lim, "Interview 42 – Ellen Jorgensen," April 22, 2020.
[270] Lim, "Interview 43 – Patrik D'haeseleer," April 30, 2020.

the community had.[271] For other founders like Genspace's Dan Grushkin, Open Bio Labs' Shaun Moshasha, and Ellen Jorgensen, they saw starting community labs as a way to not only build community, but to use these spaces as a way to engage in science communication and science education. In his interview, Dan noted that Ellen "felt like there was a dearth of science education available out in the world, and she felt like she could play a hand in that".[272] Table 7 below provides additional details on the distribution of references for each subcategory based on the community lab:

Table 7 – Access to Capabilities Driver Sub-Categories, Distribution Data and References Across Labs for Founders

Community Labs	Geographic Preference	Pooling Knowledge and Expertise	Science Communication and Education
CCL	1	1	0
Biotech without Borders	0	0	2
Genspace	0	0	2
Open Bio Labs	0	0	2

Community Lab Member Initial Drives

Overview

In total, 36 individual interviews and a single observational field data note contained 385 references on what drove current U.S. DIYBio community lab community

[271] Ibid.
[272] Lim, "Interview 17 – Daniel Grushkin," February 24, 2020.

lab members and leaders to initially participate in a community lab.[273] This analysis excluded founder data since I already discussed the initial drives of community lab founders by looking at why they started their own labs in the previous section.

The coding analysis uncovered three categories of drives that led community lab members and leaders to initially participate at a community lab: **community**, **access to capability**, and **transformative change**. Table 8 below provides a visual of the number of files and references associated with the categories that emerged from the coding analysis.

Table 8 – Member Initial Drive Categories with Associated Number of Files and References

Drive Category	# of Interviews	# of Notes	# of References
Community	35	1	215
Access to Capabilities	31	1	116
Transformative Change	22	1	54

[273] This data set includes the following observational data field note and leader and member interviews. "Field Notes 038 – Inner Harbor Project – Large Gel Electrophoresis at BUGSS," July 13, 2019; Lim, "Interview 001 – Louise," October 21, 2019; Lim, "Interview 002 – Lina," October 21, 2019; Lim, "Interview 003 – TJ," October 23, 2019; Lim, "Interview 004 – Jay," October 24, 2019; Lim, "Interview 005 – Yann," October 24, 2019; Lim, "Interview 006 – Nicole," January 17, 2020; Lim, "Interview 007 – Wangui," January 17, 2020; Lim, "Interview 008 – Eric," January 17, 2020; Lim, "Interview 009 – Deb," January 19, 2020; Lim, "Interview 010 – Sairah," January 19, 2020; Lim, "Interview 011 – Sequoia," January 26, 2020; Lim, "Interview 012 – Lisa," January 27, 2020; Lim, "Interview 014 – Lada," January 31, 2020; Lim, "Interview 015 – Tim," February 5, 2020; Lim, "Interview 016 – Andy," March 09, 2020; Lim, "Interview 018 – Afeisha," March 14, 2020; Lim, "Interview 019 – James," March 14, 2020; Lim, "Interview 020 – Danny," March 14, 2020; Lim, "Interview 021 – Leticia," March 21, 2020; Lim, "Interview 023 – Daryl," March 22, 2020; Lim, "Interview 025 – Beth," March 26, 2020; Lim, "Interview 026 – Rolf," March 28, 2020; Lim, "Interview 027 – Ramy," March 31, 2020; Lim, "Interview 028 – Wendy," April 02, 2020; Lim, "Interview 030 – Anat," April 06, 2020; Lim, "Interview 031 - Maria," April 03, 2020; Lim, "Interview 032 – Angela," April 08, 2020; Lim, "Interview 033 – Peter," April 08, 2020; Lim, "Interview 034 – Ed," April 09, 2020; Lim, "Interview 035 – Kellen," April 09, 2020; Lim, "Interview 036 – Pat," April 10, 2020; Lim, "Interview 037 – Jed," April 10, 2020; Lim, "Interview 038 – Yuriy," April 16, 2020; Lim, "Interview 039 – Chris," April 17, 2020; Lim, "Interview 040 – Ryan," April 17, 2020; and Lim, "Interview 041 – Eve," April 18, 2020.

Community Lab Member Initial Drive #1 - Community

Members most often referenced that engaging with a science-loving **community** was what drove them to join a community lab. Members like Lina and Rolf at CCL, Jay and Maria at BioCurious, Sairah and Andy at BUGSS, Beth and Leticia at Genspace, and Eve and Anat at BosLab were drawn to these spaces to do activities that resonated with their individual passions, such as teaching, learning, and building a community of citizen scientists.[274] Others like TJ and Ramy at CCL, James at Open Bio Labs, Danny and Yuriy at Biotech without Borders, and Angela at Genspace, initially joined their respective spaces because of the lab had certain social characteristics that were appealing. These social characteristics included a compatibility of values between the new member and the community lab, the emphasis that these spaces placed on engaging in community service, and an appealing community culture to the new member.[275] Finally, for members like Daryl at Biologik, Peter and Kellen at BosLab, Sequoia at BioCurious, Rolf at CCL, and Ryan at BUGSS, being able to meet new people and socialize was a major driver for joining a community lab.[276] Table 9 on the following page provides additional details on the distribution of references for each subcategory of the community driver based on the community lab:

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[274] See Lim, "Interview with Lina"; Lim, "Interview with Rolf"; Lim, "Interview with Jay"; Lim "Interview with Maria"; Lim, "Interview with Sairah"; Lim, "Interview with Andy"; Lim, "Interview with Beth"; Lim "Interview with Leticia"; "Lim, Interview with Eve"; and Lim, "Interview with Anat".
[275] See Lim, "Interview with TJ"; Lim, "Interview with Ramy"; Lim, "Interview with James"; Lim, "Interview with Danny"; Lim, "Interview with Yuriy"; and Lim, "Interview with Angela".
[276] See Lim, "Interview with Daryl"; Lim, "Interview with Peter"; Lim, "Interview with Kellen"; Lim, "Interview with Sequoia"; Lim, "Interview with Rolf"; and Lim, "Interview with Ryan".

Table 9 – Community as an Initial Driver Sub-Categories, Distribution Data and References Across Labs for Members

Community Labs	Individual Passion	Community Lab Social Characteristics	Social Interaction
BUGSS	22	17	5
BioCurious	11	8	5
Biologik	1	0	0
Biotech without Borders	1	5	4
BosLab	10	10	7
CCL	27	34	8
Genspace	24	14	10
Indie Lab	0	0	0
Open Bio Labs	6	3	1

Community Lab Member Initial Drive #2 – Access to Capabilities

Members second-most referenced initial drive to join a community lab was the opportunity to get **access to capabilities**. For some, like Yann and Louise at CCL, Sequoia and Jay at BioCurious, Wendy and Eve at BosLab, and Deb at BUGSS, community labs offered access to capabilities to pursue independent or group projects ranging from developing protocols for bio-art bacterial dyes and organizing and leading research in the Open Insulin Project to potential entrepreneurial and professional pursuits.[277] For others like Tim and Jed at BosLab, Rolf and Nicole at CCL, Leticia and Angela at Genspace, James at Open Bio Labs, Daryl at Biologik, and Ryan and Afeisha

[277] See Lim, "Interview with Yann"; Lim, "Interview with Louise"; Lim, Interview with Sequoia"; Lim, Interview with Jay"; Lim, "Interview with Wendy"; Lim, "Interview with Eve"; and Lim, "Interview with Deb".

at BUGSS, access to capabilities presented an opportunity to learn directly from science experts housed within the community lab, as opposed to needing to go to school to gain access to a lab or expertise.[278] Finally, for some like Danny and Yuriy at Biotech without Borders and Anat and Peter at BosLab, community labs were a geographic convenience to run projects closer to home than having a longer commute to a school lab or other traditional science space.[279] Table 10 below provides additional details on the distribution of references for each subcategory of the access to capabilities driver based on the community lab:

Table 10 – Access to Capabilities as an Initial Driver Sub-Categories, Distribution Data and References Across Labs for Members

Community Labs	Pursuit of Projects and Interests	Housing Equipment and Expertise	Geographic Proximity
BUGSS	9	9	0
BioCurious	7	9	0
Biologik	1	1	0
Biotech without Borders	0	0	3
BosLab	7	22	2
CCL	16	11	0
Genspace	1	7	0
Indie Lab	0	0	0
Open Bio Labs	6	6	0

278 See Lim, "Interview with Tim"; Lim, "Interview with Jed"; Lim, "Interview with Rolf"; Lim, "Interview with Nicole"; Lim, "Interview with Leticia"; Lim, "Interview with Angela"; Lim, "Interview with James"; Lim, "Interview with Daryl"; Lim, "Interview with Ryan"; and Lim, "Interview with Afeisha".
279 See Lim, "Interview with Danny"; Lim, "Interview with Yuriy"; Lim, "Interview with Anat"; and Lim, "Interview with Peter".

Community Lab Member Initial Drive #3 – Transformative Change

The least-referenced initial drive for members joining a community lab was to bring about transformative change to the way that citizens are taught, interact with, and produce science outside of traditional science spaces. For members like James at Open Bio Labs, Kellen, Anat, and Wendy at BosLab, Lina at CCL, Afeisha at BUGSS, Yuriy at Biotech without Borders, and Leticia, Beth, and Angela at Genspace, they joined community labs to do their part in democratizing the life sciences and providing a viable alternative for everyday citizens to experience, learn, and do science outside of traditional science spaces.[280] Other individuals like TJ and Yann at CCL, Andy and Ryan at BUGSS, Jed at BosLab, and Sequoia at BioCurious were drawn to these spaces because they were novel – these spaces were trying something new and revolutionary, and they wished to be a part of it.[281] Table 11 on the following page provides additional details on the distribution of references for each subcategory of the access to capabilities driver based on the community lab:

[280] See Lim, "Interview with James"; Lim, "Interview with Kellen"; Lim, "Interview with Anat"; Lim, "Interview with Wendy"; Lim, "Interview with Lina"; Lim, "Interview with Afeisha"; Lim, "Interview with Yuriy"; Lim, "Interview with Leticia"; Lim, "Interview with Beth"; and Lim, "Interview with Angela".

[281] See Lim, "Interview with TJ"; Lim, "Interview with Yann"; Lim, "Interview with Andy"; Lim, "Interview with Ryan"; Lim, "Interview with Jed"; and Lim, "Interview with Sequoia".

Table 11 – Transformative Change as an Initial Driver Sub-Categories, Distribution Data and References Across Labs for Members

Community Labs	Creating an Alternative to Traditional Science Spaces	Novel/Revolutionary
BUGSS	2	4
BioCurious	2	2
Biologik	0	0
Biotech without Borders	1	1
BosLab	10	6
CCL	1	4
Genspace	4	7
Indie Lab	0	0
Open Bio Labs	1	1

Community Lab Member Drives

Overview

In total, 35 individual interviews and 64 observational field data notes contained 714 references on what currently drives members to continue participating in their community lab.[282] In this section of the analysis, founders were also included to the lab member pool as founder drives may have changed over time.

[282] This data set includes observational data field notes and interview data. Field notes include Lim, "Field Notes 002, 004, 008 – 016, 019 – 021, 023, 024, 026, 028, 030 – 035, 038 – 050, 053 – 056, 058, 059, 062 – 068, 070 – 074, 076, 080 – 085, 087, and 088". Interview data includes Lim, "Interview with Lina,"; Lim, "Interview with TJ,"; Lim, "Interview with Jay,"; Lim, "Interview with Yann,"; Lim, "Interview with Wangui,"; Lim, "Interview with Eric,"; Lim, "Interview with Deb,"; Lim, "Interview with Sairah,"; Lim, "Interview with Sequoia,"; Lim, "Interview with Lisa,"; Lim, "Interview with Tom,"; Lim, "Interview with Lada,"; Lim, "Interview with Andy,"; Lim, "Interview with Dan,"; Lim, "Interview with Afeisha,"; Lim, "Interview with James,"; Lim, "Interview with Danny,"; Lim, "Interview with Leticia,"; Lim, "Interview with Jameson,"; Lim, "Interview with Shaun,"; Lim, "Interview with Beth,"; Lim, "Interview with Rolf,"; Lim, "Interview with Ramy,"; Lim, "Interview with Wendy,"; Lim, "Interview with Bill,"; Lim, "Interview with Anat,"; Lim, "Interview with Maria,"; Lim, "Interview with Angela,"; Lim, "Interview with Kellen,"; Lim, "Interview with Pat,"; Lim, "Interview with Jed,"; Lim, "Interview

The coding analysis uncovered three categories of drives that led community lab members and leaders to currently participate at a community lab: **community**, **access to capability**, and **transformative change**. Table 12 below provides a visual of the number of files and references associated with the categories that emerged from the coding analysis.

Table 12 – Current Member Drive Categories with Associated Number of Files and References

Drive Category	# of Interviews	# of Notes	# of References
Community	35	55	507
Access to Capabilities	22	46	165
Transformative Change	10	17	42

Community Lab Member Current Drive #1 – Community

Most current members referenced that engaging with a science-loving **community** is what drives them to continue participating in a community lab. Many members across all the community labs researched in this dissertation continue to be drawn to these spaces to do activities that resonated with their individual passions, such as teaching, learning, and building a community of citizen scientists.[283] Others continue

with Yuriy,"; Lim, "Interview with Chris,"; Lim, "Interview with Ryan,"; and Lim, "Interview with Ellen".

[283] For examples, see Lim, "Interview with Lina,"; Lim, "Interview with TJ, "; Lim, "Interview with Jay,"; Lim, "Interview with Sairah,"; Lim, "Interview with Lisa,"; Lim, "Interview with Tom,"; Lim, "Interview

to participate in these spaces because the lab has certain social characteristics that are appealing. These social characteristics include a compatibility of values between the new member and the community lab, the emphasis that these spaces place on engaging in community service, and an appealing community culture to the current member.[284] Finally, some members continue to go to their community lab because they love the social interactions that occur in these spaces, including meeting new people and talking about new and interesting things.[285] Table 13 below and on the following page provides additional details on the distribution of references for each subcategory of community as a current driver for members based on the community lab:

Table 13 – Community as a Current Driver Sub-Categories, Distribution Data and References Across Labs for Members

Community Labs	Individual Passion	Community Lab Social Characteristics	Social Interaction
BUGSS	22	17	5
BioCurious	11	8	5
Biologik	1	0	0
Biotech without Borders	1	5	4
BosLab	10	10	7
CCL	27	34	8
Genspace	24	14	10

with Dan,"; Lim, "Interview with Danny,"; Lim, "Interview with Jameson,"; Lim, "Interview with Rolf,"; Lim, "Interview with Anat,"; Lim, "Interview with Angela,"; Lim, "Interview with Chris,"; and Lim, "Interview with Ellen".

[284] For examples, see Lim, "Interview with Jay,"; Lim, "Interview with Yann,"; Lim, "Interview with Sequoia,"; Lim, "Interview with Lada,"; Lim, "Interview with Andy,"; Lim, "Interview with Dan,"; Lim, "Interview with James,"; Lim, "Interview with Danny,"; Lim, "Interview with Beth,"; Lim, "Interview with Rolf,"; Lim, "Interview with Ramy,"; Lim, "Interview with Wendy,"; Lim, "Interview with Maria,"; Lim, "Interview with Pat,"; Lim, "Interview with Ryan,"; and Lim, "Interview with Ellen".

[285] For examples, see Lim, "Interview with Jay,"; Lim, "Interview with Eric,"; Lim, "Interview with Lisa,"; Lim, "Interview with Andy,"; Lim, "Interview with Anat,"; and Lim, "Interview with Maria".

Indie Lab	0	0	0
Open Bio Labs	6	3	1

Community Lab Member Current Drive #2 – Access to Capabilities

Again, members second-most referenced drive to continue participating in a community lab is the opportunity to get **access to capabilities**. For some, community labs offer access to capabilities for developing products like Sequoia's bio-art bacterial dyes and Danny's development of a self-regulating plant incubator DIY materials and electronics like Arduino boards.[286] For others, community labs offer the opportunity to engage in large-scale projects like the Barcoding the Inner Harbor and Open Insulin Projects to better understand the environment and address systemic inequalities.[287] Finally, some members also continue to go to these spaces because they are drawn to the expertise that exist in these spaces – expertise that they can directly learn and apply through peer-to-peer interactions, such as CCL members teaching Rolf how to do DNA sequencing and Jay learning basic biology from PhD level biologists to become a more active participant at BioCurious.[288] Table 14 below provides additional details on the distribution of references for each subcategory of the access to capabilities driver based on the community lab:

[286] Arduino is an open-source electronic prototyping platform that allows users to make easy-to-use hardware and software products. For more details, see Lim, "Interview with Sequoia," and Lim, "Interview with Danny".
[287] See Lim, "Interview with Yann,"; Lim, "Interview with Sairah,"; Lim, "Interview with Afeisha,"; and Lim, "Interview with TJ".
[288] See Lim, "Interview with Rolf," and Lim, "Interview with Jay".

Table 14 – Access to Capabilities as a Current Driver Sub-Categories, Distribution Data and References Across Labs for Members

Community Labs	Pursuit of Projects and Interests	Housing Equipment and Expertise
BUGSS	21	40
BioCurious	7	5
Biologik	1	0
Biotech without Borders	0	3
BosLab	16	23
CCL	10	10
Genspace	6	5
Indie Lab	4	3
Open Bio Labs	0	2

Community Lab Member Current Drive #3 – Transformative Change

The least-referenced initial drive for members continuing to participate in a community lab is to bring about transformative change to the way that citizens are taught, interact with, and produce science outside of traditional science spaces. For some members, they are driven to continue participating in community labs to do their part in democratizing the life sciences and providing a viable alternative for everyday citizens to experience, learn, and do science outside of traditional science spaces.[289] For others, they continue to participate in these spaces because they believe they continue to be novel – these spaces were trying something new and revolutionary, and they wish to be a part of

[289] See Lim, "Interview with Lisa"; Lim, "Interview with Jameson"; Lim, "Interview with Rolf"; Lim, "Interview with Bill"; Lim, "Interview with Maria"; Lim, "Interview with Angela"; Lim, "Interview with Kellen"; and Lim, "Interview with Chris".

it.[290] Table 15 below provides additional details on the distribution of references for each subcategory of the access to capabilities driver based on the community lab:

Table 15 – Transformative Change as the Current Driver Sub-Categories, Distribution Data and References Across Labs for Members

Community Labs	Creating an Alternative to Traditional Science Spaces	Novel/Revolutionary
BUGSS	0	5
BioCurious	2	0
Biologik	2	0
Biotech without Borders	0	1
BosLab	4	2
CCL	2	1
Genspace	1	0
Indie Lab	2	3
Open Bio Labs	0	1

Biorisk Threat Evaluation of U.S. DIYBio Community Labs through Drive Data

DIYBio Transformative Change as Disruptive Ideology

The drives data of U.S. DIYBiology community labs indicate that founders and participants started and continue to operate in these spaces to disrupt and change the way people interact and engage with science. 6 out of 7 founders (86%) indicated that they were driven to start community labs to disrupt the status quo of scientific practice. This desire to disrupt the status quo of science and increase the autonomy and contributions of citizens

[290] See Lim, "Interview with Lisa,"; Lim, Interview with Jameson,"; and Lim, "Interview with Bill".

into science through acts of transformative change that democratize technologies aligns well with the Biopunk's Manifesto – an online document commonly referenced as enshrining the ethos of the DIYBio movement.[291]

Founders of community labs see themselves as pioneers with a vision – a vision to democratize the life sciences and, thus, make it more accessible to the broader public. For founders, this desire to democratize and create an open science space stems from two main causes. One cause is where founders either experience or witness how traditional science institutions are not meeting their personal needs or the needs of others. In the case of Patrik, a bioinformaticist and co-founder of CCL, his professional life did not bring him fulfillment. Further, he realized that there were very few avenues for him to develop a knowledge of biology that he personally was interested in:

> "For somebody with my background and my level of career, the only other two options out there would have been going back and taking undergraduate classes, right? Because you're going through the academic track, there are all of these pre-requisites that you have to build up first, right?"[292]

The other cause is where founders wish to disrupt what they believe is a societal perception that science is hard, inaccessible, and not meant to be understood or practiced by everyone. As a PhD-level molecular biologist and the founder of community labs in the Brooklyn area, Dr. Ellen Jorgensen saw how anti-science sentiments were inter-related with the seeming opacity of modern science:

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[291] Meredith Patterson, "A Biopunk Manifesto," *LiveJournal*, January 30, 2010, https://maradydd.livejournal.com/496085.html. Accessed March 23, 2021.
[292] Lim, "Interview with Patrik,".

"I saw public sentiment with the anti-GMO movement, the anti-vaxx movement as kind of the pitchforks and torches coming up the hill to shut down modern science. And it really disturbed me, this anti-science attitude. And so, from the perspective of a professional scientist, I was intrigued by the idea of community labs…of making people less afraid about this through hands-on participation."[293]

Jamie Dungan, founder of Biologik, offers the flipside of Ellen's concerns about the opacity of science and the issues it causes. Jamie, whose academic background is in German, had no real science experience before he founded his community lab. It was only through his exposure to iGEM and seeing teenagers doing synthetic biology that he realized that he himself might not only be able to do science, but help others realize that science is not for the privileged few:

"So I just want to have that attitude and thought for a lot of kids that science isn't this intimidating thing that's outside of them, or beyond them, or they're too stupid to learn, or they don't have the skillset to do. It was something they did as a kid and they could get back into it at any moment if they wanted to."[294]

Therefore, the act of founding a community lab can be interpreted as a disruptive act – one which seeks to disrupt to the status quo of who can do science, as well as how it is taught, experienced, and executed.

In the broader community lab population, transformative change was an initial driver for over half the individuals interviewed in this survey (51%). However,

[293] Lim, "Interview with Ellen".
[294] Lim, "Interview with Jamie".

transformative change as a current drive for community lab participation has significantly decreased (23%). Despite this change over time, transformative change is a drive that continues to encourage members to participate in these spaces towards disruptive ends. For some, like Lina, these spaces provide opportunities to teach and do research that she no longer has access to after she graduated from college:

> "I've always liked biology and liked research, so it's difficult to get into research, I think, outside of universities or academic settings, so I think, 'I will go into this later', but that's why I like these labs."[295]

For others, community labs represent a space where citizens can work together to empower communities and address what members view as systemic injustice. For Louise, who has a PhD in biochemistry, community labs should strive to disrupt existing systems of inequity and empower communities through projects like Open Insulin:

> "It's great to have a place like CCL so that people can spend the whole summer there and have an internship at the lab and gain experience, so this is kind of outreach. But you need to also do more social change. That's what I really like about Open Insulin. We try to do structural changes and not just cheap insulin. Our point is not only the price of insulin, but also why it is expensive, and if you do the exact same thing, it will become expensive again."[296]

Therefore, U.S. DIYBiology community labs are two things. First, their very existence serves as a disruptive act against traditional science by attempting to democratize

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[295] Lim, "Interview with Lina".
[296] Lim, "Interview with Louise".

it. Second, U.S. DIYBiology community labs serve as spaces that further galvanize participants to disrupt the status quo through activities that seek to promote transformative change, such as the Open Insulin Project. Therefore, the design data indicates that U.S. DIYBiology community labs engage in disruptive actions to achieve their disruptive ideological goals – a world that overturns the status quo of traditional science by democratizing its access, learning, and use to everyone.

DIYBio Community Labs and its Inclinations toward Violent Acts

To date, there have been no cases of a biorisk issue or acts of violence that arose from U.S. DIYBio community lab spaces publicized in the literature.[297] While this does not necessarily mean that change could not happen over time or that under-reporting is occurring, this is a positive indication that U.S. community labs have not acted in negative ways that were publicized by the biorisk community or the media. This is particularly encouraging given the inherent bias that these communities have concerning the DIYBio community, which present these spaces as lacking risk awareness and other biorisk considerations despite presenting "little-to-no evidence for any of these claims".[298]

The drive data in my dissertation research that provides the most insight into this issue of a propensity for violence is the community drive dataset. Amongst the 7 founders of community labs interviewed in this study, 5 (71%) of them noted that they were

[297] For examples, see Charisius et al., "Becoming Biohackers: The Long Arm of the Law," *BBC*, January 23, 2013, https://www.bbc.com/future/article/20130124-biohacking-fear-and-the-fbi. Accessed March 23, 2021; Gerstein, "DIY Bio: Separating Fact,"; and *Independent Biotech: The Innovation-Regulation Dilemma*, Livermore, CA: Department of Energy, 2016, 13 – 14.
[298] Lalitha Sundaram, "Biosafety in DIY-Bio Laboratories: From Hype to Policy," *EMBO Reports*, e52506, 2021, 1 – 5.

motivated to start a lab to start, build, or expand a community. Shaun, who founded Open Bio Labs, highlights how building a community interested in science was so important to him following a meeting with Ellen Jorgensen of Genspace:

> "I met Ellen Jorgensen and then a couple of other members of the community bio movement, and that was the first time I had heard about community biology and I thought, 'Hey. This stuff is awesome. I want to play in a lab like this, too. So in 2014, I started a MeetUp group, and I started having these bi-weekly meetings just to talk about synthetic biology and the future of biotechnology. I think, over the course of 6 months, the group grew organically to over 100 people on the MeetUp group, and I decided, 'I can always get a job later on, but now is my time to try to do Open Bio Labs."[299]

Tom Burkett of BUGSS also was similarly inspired to help build the DIYBio and science enthusiast community after he attended an event at a community art space – an event which left him wondering why there was no similar community space for science.[300]

Therefore, while the ideology and actions of U.S. DIYBiology community are meant to be disruptive to the scientific status quo, the means that this community seeks to create change appears to be about *building* communities, as opposed to destroying them in advancement of their goals. This is further supported by how community lab founders and members in the United States viewed building a close relationship between these spaces and law enforcement as a positive thing – 8 out of 43 interview (19%) contained references

[299] Lim, "Interview with Shaun".
[300] Lim, "Field Notes 007 – Conversation with Tom Burkett," April 13, 2019.

to the FBI, and all of these references were positive.[301] Founders like Tom Burkett noted that the FBI did outreach to the community early, and that this relationship grew over time to one where the FBI could function both as an advocate for community labs, as well as act like a potential shield against negative perceptions of the community from outside observers.[302] BioCurious leader Eric even noted how the lab uses its connections with the FBI to keep away nefarious and questionable actors from entering and operating in the space:

> "We're very upfront about our relationship with the FBI. I would always say to folks, 'You know, if the FBI wanted to come in here and sequence everything in the lab, great! You know, I'd be interested in that data, too. I think that'd be wonderful, and they have an open invite to do any of that.' So when you say that to a new member, if you're nefarious, I would think they would be like, 'I probably don't want to work here, then.'"[303]

This effort to manage community labs in a safe, secure, and peaceful way is not solely dependent on external oversight. Certain community labs also have mechanisms to monitor and expel individuals who do not conform to the cultural and operational expectations of these spaces. Maria at BioCurious explained how this type of self-governed oversight works in the Bay Area:

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[301] See Lim, "Interview with Yann,"; Lim, "Interview with Eric,"; Lim, "Interview with Tom"; Lim, "Interview with Maria"; Lim, "Interview with Peter"; Lim, "Interview with Ed"; Lim, "Interview with Kellen,"; and Lim, "Interview with Ellen".

[302] Ibid.

[303] Lim, "Interview with Eric".

"So in the Bay Area, if somebody is actually banned from the lab, the idea is that the other labs wanted to know about folks who were not good community members who tried to bounce from space to space. So we instituted a reciprocal ban with Noisebridge, Counter Culture Labs, and BioCurious. And the idea is we didn't want somebody who is not a good community member bouncing from lab to lab. One member was very verbally abusive to some of our members and also very unsafe as far as good lab safety. We want to make sure that those types of people…our community members are aware of."[304]

Community lab leadership and founders have also engaged in outreach to the biorisk community beyond the FBI. According to Dan Grushkin, co-founder of Genspace, this was done in response to the many assumptions of the community within policy circle – assumptions that included community labs as spaces that produce illicit drugs and harm others:

"'When are they [the community labs] going to start making illicit drugs? When are they going to start making pandemics? When are they going to start harming people?' Which couldn't be farther from our capacities, and it couldn't be farther from our intentions. So a lot of our early work alongside of getting started and just trying to figure out what it is we are and what we're doing and how we're doing it and how we're paying for it and why it's important in the world was also trying to defend ourselves against this media onslaught. And so, within, I would say, a year of getting ourselves off the ground, spending a lot of time in Washington talking to

[304] Lim, "Interview with Maria".

> policymakers and talking to the policy community to explain that this isn't…this is actually an opportunity, not a threat."[305]

From this outreach effort, Grushkin sees the 2013 Wilson Center report on DIYBio as a point of success that he believes calmed the policy community down about concerns of the community by addressing misperceptions and highlighting the peaceful nature and activities occurring in these spaces.[306]

Given the lack of evidence of past biorisk events occurring in DIYBio spaces, as well as the insights derived from the drive data, there is no evidence at this current time that shows U.S. DIYBio community labs as having a propensity for violence. The evidence points in the opposite direction. The drive data suggests that rather than achieving their objectives through destructive means, community lab founders seek to disrupt science by building communities for citizens. Further, community labs have a positive relationship with law enforcement, and even use their relationship with the FBI to discourage potentially nefarious participants from entering their spaces. If people enter these spaces and are found to not be suitable due to biorisk concerns, self-governance mechanisms like black lists exist to restrict access to community labs. Finally, the community has done additional outreach to policymakers to emphasize how the DIYBio community intends only peaceful and non-harmful activities.

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[305] Lim, "Interview with Dan".
[306] Ibid.

Conclusion

The biorisk community has typically viewed the DIYBio community as a potential biorisk threat. Given the way the DIYBio community talks about the disrupting the status quo, the biorisk narrative has often conflated this desire to radically democratize technology with an assumption that this community may have malicious drives and effect this change through violent means. This chapter concludes with some brief implications and limitations on the biorisk threat assessment using U.S. community lab drive data.

Implications

In the case of U.S. DIYBio community lab drives, the biorisk threats associated with these spaces are over-exaggerated. While the community does show evidence of a disruptive ideology and a willingness to engage in disruptive acts, it lacks a fundamental propensity for violence: a clear requirement from the bioterrorism literature for a biorisk threat to be credible.

Further, the drive data suggests that current drives for participating in a community lab are less about effecting transformative change, and more about engaging in community-building, socializing, and working together. This may indicate a fundamental switch in how community labs initially viewed themselves versus how they perceive themselves now. Eric at BioCurious highlighted this phenomenon through the lens of how social movements fragment and change over time:

> "There are always going to be spectrums, so you're going to have radicals, and you're going to have moderates, and you're going to have everyone in between.

And so the radicals push on these ideas and concepts and these outlandish things for their own intents and purposes, right? You can think of tons of examples in the DIYBio community of people doing that. And then you have the moderates, and I would consider myself a moderate, that sort of say that DIYBio is doing this thing where we're trying to educate and look at all the great things that are happening, and there's this tug of war between the two camps. But there has been this growth in the radicals or, at first, we were sort of the folks in the moderate camp, or a little bit edgy. But now it's sort of swung pretty wide with the things people are doing that are sort of more radical."[307]

Interestingly, the fragmentation that Eric discusses above is one that indicates that community lab members may be on the moderate to conservative end of the spectrum at this point in the DIYBio community. This observation raises questions of generalizability for whether the drive data associated with U.S. community labs holds true across other DIYBio groups.

Limitations

This analysis has three main limitations. As discussed in the implications section, there are questions about being able to generalize the findings from this data to other groups within the DIYBio community. It is also likely difficult to generalize this data to community labs in other regions due to how different regions operate with different laws

[307] Lim, "Interview with Eric".

and likely have different interests in activities. Therefore, this analysis is only truly applicable to DIYBiology community labs based in the U.S.

Second, while the bioterrorism literature offered the best comparison for assessing biorisk threat in the context of motivations and drives, the use of it to build a biorisk threat assessment of U.S. DIYBiology community labs does present with a flaw - the DIYBiology community is not a violent non-state actor group and is not officially declared through any government agency as a terrorist organization. Therefore, while some useful data and insights were generated in this chapter based on the drives of U.S. community labs founders and members, this limits the applicability that this dissertation would have directly on the bioterrorism and violent non-state actor literatures.

Third, the drives data I gathered for this dissertation research was entirely qualitative and acquired through personal on-site visits for observational data, and virtual interviews for interview data. My ability to gather this data was enabled largely through my prior interactions and relationship-building with the community 3 years prior to the start of my dissertation research. The large dependence on personal experiences and memories, particularly for the interview data, does introduce the issue of self-reported data bias.

CHAPTER FIVE – THE DESIGN OF US COMMUNITY LABS AND THEIR BIORISK THREAT IMPLICATIONS

Introduction

Chapter 5 focuses on analyzing the biorisk narrative's assumption that technical information and equipment are all that are necessary to successfully complete complex scientific tasks and projects. This chapter will begin by providing a brief overview of the existing STS literature to highlight how 3 socio-organizational factors positively affect the development, use, and transfer of tacit knowledge and expertise, including, 1) organizational factors that allow people to work closely together and have the autonomy to discuss issues with others involved at various other points in a complex scientific task; 2) a knowledgeable leader that has the resources and ability to actively cultivate a positive, transparent community environment based on trust and can advocate ongoing projects to outside stakeholders; and 3) stable and adequate finances to accomplish the project at hand. This chapter then provides a basic overview of the design of community labs, including how they are organized, and how they are financed. I will proceed to the biorisk threat evaluation with an overview of the Inner Harbor Project community lab project. I will then use this project as a vehicle to highlight how organizational factors, leadership, and finances play into the success and/or failure of complex scientific projects in these spaces.

I arrived at 5 main findings from the design data. First, community labs greatly value creating a community that is open, communicative, and encourages sharing across individuals within labs and between outside organizations. Second, these spaces operate under a hybrid participation model where leaders exist to provide guidance and direction but has expectations of members to be self-starters. Third, community labs are lean organizations that experience significant financial hardship despite raising funds through membership fees, foundation grants, and donations. Fourth, the volunteer nature of being a leader presents bandwidth challenges for project leads and lab leadership to fully devote their time to managerial tasks. Fifth, the nature of community labs as being a hobby space, as opposed to a professional space, presents social and personnel challenges to accomplishing complex scientific tasks.

Finally, this section concludes with the implications and limitations of these findings. As part of its mission to democratize biology, community labs are also interested in being taken seriously as producers of good science. To this end, the community has built labs with available equipment, online information, and expertise housed in members and leadership. Despite the desire to create and produce good science, there has been little progress on this front. Insights from the STS literature applied to the design data of this dissertation provide explanations for why this may be the case. Despite an open and trusting organizational environment that allows people to speak freely, gain feedback, and collaborate with others, there are significant organizational, managerial, and financial intangible barriers these spaces need to still overcome to successfully accomplish complex scientific tasks and projects. Therefore, despite limitations associated with sampling, and potential bias and observer effects, this analysis concludes that the biorisk assumption that U.S. DIYBio community labs can easily accomplish complex scientific tasks and projects since they house technical information and equipment is erroneous and should be reconsidered.

The Biorisk Perspective – Complex Scientific Projects Only Require Technical Knowledge and Equipment for Success

Capabilities for editing and manipulating microbial genomes have increased significantly since the work of Paul Berg in 1971 – the first scientist ever to create recombinant DNA from more than one species.[308] Subsequent breakthroughs in genome editing technology, culminating most recently in revolutionary technology known as CRISPR developed by Drs. Jennifer Doudna and Emmanuelle Charpentier in 2011, highlights how quickly technologies can change in precision, capability, cost, and expertise requirements in less than half a century.[309]

This case of how technologies can rapidly advance, change, and become distributed significantly contributes to how the biorisk community perceives risks. Combined with the perceived ubiquity of information available through the internet, the biorisk narrative assumes that with the right equipment, materials, and information, complex scientific tasks and projects can be done anywhere, at any time, and in any situation. Therefore, the world that the biorisk narrative constructs is one where everyone

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[308] "History of Genetic Engineering and the Rise of Genome Editing Tools," *Synthego,* https://www.synthego.com/learn/genome-engineering-history. Accessed March 24, 2021.
[309] Brad Plumer, Eliza Barclay, Julia Belluz, and Umair Irfan, "A Simple Guide to CRISPR, One of the Biggest Science Stories of the Decade," *Vox*, December 27, 2018, https://www.vox.com/2018/7/23/17594864/crispr-cas9-gene-editing. Accessed March 24, 2021.

has access to do any complex scientific task with no oversight or intervention opportunities.

This is world that the biorisk community is adamantly opposed to since the implications are potentially devastating – anyone, from anywhere, at any time, may be using easily accessible and deskilled technical capabilities and information to research, develop, weaponize, and deploy biological agents. Unfortunately, this is the world that the biorisk community assumes is occurring given the emergence of the DIYBio community – a group that has access to equipment and information with no oversight to prevent negative biological events. This assumption perfectly aligns with Vogel's work on the biotech revolution model – the dominant model that the biorisk community uses to frame its understanding of emerging biological threats.[310]

However, the STS literature argues that having the necessary equipment and written instructions is not sufficient to successfully complete complex scientific tasks and projects. These scholars argue that technical capabilities should only compromise one part of a larger analysis: an analysis that considers socio-technical dynamics such as tacit knowledge and expertise, as well as organizational, managerial, social, and economic factors.[311]

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[310] Vogel, "Reframing Biosecurity", 45 – 48.

[311] See Vogel, *Phantom Menace or Looming Danger*, Loc 1291 – 1986; Iris Hunger, Jez Littlewood, Caitriona McLeish, Piers Millett, and Ralf Trapp, "Roundtable: The Future of Biothreat Governance," in *Biological Threats in the 21st Century*, London, UK: Imperial College Press, 2016, 431 – 450; Ben Ouagrham-Gormley, *Barriers to Bioweapons* (2014), 17 – 63; and Sonia Ben Ouagrham-Gormley and Kathleen M. Vogel, "The Social Context Shaping Bioweapons (Non)proliferation," *Biosecurity and Bioterrorism* 8, no. 1 (2010), 9 – 24; Sonia Ben Ouagrham-Gormley and Shannon R. Fye-Marnien. "Is CRISPR a security threat?". In *Defense Against Biological Attacks*, 233 - 251. Springer, Cham, 2019; Kathleen M. Vogel and Sonia Ben Ouagrham-Gormley, "Anticipating Emerging Biotechnology Threats: A Case Study of CRISPR," *Politics and the Life Sciences* 37, no. 2, 203 – 219; and Kendall Hoyt, *Long Shot: Vaccines for National Defense*, Cambridge, MA: Harvard University Press, 2012: Loc 529 – 858.

Tacit knowledge and expertise refer to a category of information that is gained through repeated practice and experience over a long period of time. Further, tacit knowledge is not just about individual knowledge – achieving success in complex scientific tasks requires tacit knowledge and expertise to be built *within* and *between* all participants as well. In the context of biological weapons research and development, Ben Ouagrham-Gormley notes that achieving this type of knowledge creation, transfer, and use is exceptionally difficult. Further, Hoyt, Ben Ouagrham-Gormley emphasize how difficult it is to generate and pass along tacit knowledge due its personal, local, geographically bound, and "sticky" nature.[312]

Scholars studying the intersection of successful science and tacit knowledge issues discuss how the ability to leverage, develop, and use both individual and collective forms of tacit knowledge is key to achieving a successful outcome for complex scientific tasks and projects. Work in this field highlights three elements that contribute significantly to the potential success or failure of complex scientific tasks, including 1) the cultivation of a community organization where members trust and work closely with team members while also allowing members to interact and coordinate activities across all stages of a complex scientific endeavor; 2) the presence of an active manager who creates and reinforces desirable organizational conditions for collaboration and information sharing while also acting as an advocate of the project to external stakeholders; and 3) the ability to obtain sufficient and stable funding.[313]

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[312] See Hoyt, *Long Shot*, Loc 71 – 87; Ben Ouagrham-Gormley, *Barriers to Bioweapons* (2014), 17 – 24; and Vogel, *Phantom Menace or Looming Danger*, Loc 1925.

[313] Much of this work is pulled from Dr. Ben Ouagrham-Gormley, an STS and biodefense scholar who has studied the intersection of successful execution of complex scientific tasks and socio-organizational

When looking at the existing literature on DIYBio community lab projects, the biorisk narrative assumption that equipment and information are the only requirements for a successful outcome is not supported - if the assumption of the biorisk narrative is correct, we would expect to see U.S. community labs have, within their technical capabilities, many successful scientific projects out of these spaces. However, this assumption does not bear out in reality. The Glowing Plant Project, which was initially housed in BioCurious and sought to introduce 6 genes into plants to make them glow, was deemed a failure by the project's creator in 2017 despite having crowdsourced nearly half a million dollars from Kickstarter and having a fully equipped lab space to do their work.[314] The Open Insulin Project, a famous and global DIYBio project hosted at CCL where members are looking to produce an open-source method so diabetics can produce their own low-cost insulin, started in 2015 but has yet to complete its goal – the most recent project update in 2019 indicates that they *might* have produced a molecule through their engineered yeast that is the same size as insulin.[315]

Therefore, this dissertation looked at the three design elements highlighted from the STS literature to determine how these factors may affect the success or failure of a community lab project, which include including 1) the cultivation of a community

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barriers to tacit knowledge. For examples, see Ben Ouagrham-Gormley, *Barriers to Bioweapons*; Ben Ouagrham-Gormley and Vogel, "The Social Context Shaping Bioweapons (Non)Proliferation,"; Ben Ouagrham-Gormley and Fye-Marnien, "Is CRISPR a Security Threat,"; and Vogel and Ben Ouagrham-Gormley, "Anticipating Emerging Biotechnology Threats".

[314] Sarah Zhang, "Whatever Happened to the Glowing Plant Kickstarter?," *The Atlantic*, April 20, 2017, https://www.theatlantic.com/science/archive/2017/04/whatever-happened-to-the-glowing-plant-kickstarter/523551/. Accessed March 24, 2021.

[315] Grant Burningham, "The Price of Insulin has Soared. These Biohackers Have a Plan to Fix It," *Time*, October 24, 2019, https://time.com/5709241/open-insulin-project/. Accessed March 24, 2021.

organization where members trust and work closely with team members while also allowing members to interact and coordinate activities across all stages of a complex scientific endeavor; 2) the presence of an active manager who creates and reinforces desirable organizational conditions for collaboration and information sharing while also acting as an advocate of the project to external stakeholders; and 3) the ability to obtain sufficient and stable funding.

The Design of U.S. DIYBio Community Lab Participants

I obtained information on the design of community lab participants through two means. First, I used interview data as each interview contained questions about how the interviewees viewed their community lab's organizational structure, the activities, projects, and interactions that they had in these spaces, and if they had knowledge of the financial situation of their space. Second, I used on-site observational data to see, interact with, and personally experience how these spaces are organized, what activities and projects occur in these spaces, and gain information on the space's financial situation. In total, there were 8 founders or co-founders of community labs who were interviewed in this study, along with 18 leaders and 18 participants.

Community Lab Design Characteristics

Hierarchy and Leadership

All the community labs studied in this dissertation had both leaders and members that made up the composition of the space, with most participants being volunteers – this point will be elaborated on in the finances section of this chapter. The concept of leader was formalized in these cases with titles, as well as responsibilities that came along with the leadership role. For all the community labs researched in this dissertation, formal leadership titles and responsibilities was a legal requirement – all these community labs I researched were all registered 501©3 non-profits. Therefore, each community lab I visited was legally required to have a 3-person minimum board of directors, including a chairperson, secretary, and treasurer.[316] Across all the community labs I visited, these board members anywhere from monthly to quarterly to discuss the situation at the lab, potential areas of activity the lab should focus on, and making sure the finances are in line.[317]

The board provided the overarching vision of the lab's identity, what direction it should go, and what its goals were. The leader that typically ran the day-to-day operations and made sure the board's vision was fulfilled was either the executive director or president of the space. Across all the community labs I went to, this role required a single individual to take on a great amount of responsibility and, with one exception, no compensation for their time or effort. From the 7 interviews I conducted with current and former executive directors or presidents, their tasks included 1)

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[316] For examples, see "BUGSS: Staff and Board," *BUGSS*, https://bugssonline.org/staff-and-board/. Accessed March 26, 2021; "People," *Genspace*, https://www.genspace.org/staff-1, Accessed March 26, 2021; "Leadership," *Indie Bio*, http://www.indielab.co/leadership. Accessed March 26, 2021; "About," *BioCurious*, https://biocurious.org/about/. Accessed March 26, 2021; and "About," *BosLab*, https://www.boslab.org/about. Accessed March 26, 2021.
[317] See Lim, "Interview with Tom,"; Lim, "Interview with Lisa,"; Lim, "Interview with Jay," Lim, "Interview with Lada," Lim, "Interview with Tim," Lim, "Interview with Danny," Lim, "Interview with Ramy," Lim, "Interview with Wendy," Lim, "Interview with Maria," Lim, "Interview with Kellen," Lim, "Interview with Ellen,"; and Lim, "Interview with Patrik".

preparing for, presenting at, and completing tasks assigned to them from board meetings; 2) grant-writing; 3) teaching classes ranging from basic science lectures to lab skills; 4) being present when the lab is open to provide feedback, expert advice, and oversight in the lab; 5) keeping snacks and beverage stocked for lab participants; 6) cleaning up and closing the lab; 7) providing feedback and oversight on safety reviews for proposed projects; 8) initiating and participating in community outreach events; and 9) attending public events and fundraisers to advocate for the lab and solicit potential funding.[318]

Below the executive director, some organizations had more specialized positions such as a lab manager, a communications director, and leads for different categories of projects. This was most apparent at Genspace, which had sufficient funding to pay salaries for four leadership positions: executive director, lab safety manager, program manager, and communications director.[319]

Finally, community labs have members that participate in lab activities and events. These members may be paying members with full access to the lab for their own projects or to participate in community labs. Some members, while not paying members, can participate in community lab projects to stay true to the space's mission to democratize technology and because there are never too many people to help on a project.[320]

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[318] See Lim, "Interview with Lisa," Lim, "Interview with Tom," Lim, "Interview with Lada," Lim, "Interview with Dan," Lim, "Interview with Shaun," Lim, "Interview with Beth," Lim, "Interview with Wendy," and Lim, "Interview with Ellen".

[319] See Lim, "Interview with Beth,"; Lim, "Interview with Angela,"; and Lim, "Interview with Leticia".

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Self-Starter Culture

While a hierarchy does exist in community labs, the volunteer nature of participation in these spaces makes the leadership/membership divide largely irrelevant in terms of participating in existing activities. Members can typically enjoy participating in events and projects that they are interested in and are often encouraged to start their own projects in these spaces.

The organizational structure data suggests that this comes from two main reasons. First, as alluded to in the section on hierarchy, executive directors and presidents of community labs have little time or opportunity to take on additional tasks. In my interview with him in April, Anat discusses how much of a burden BosLab president Wendy has taken on in her role:

> "I think the one change I want to see is just more initiative from people to just lessen Wendy's burden. For example, Wendy also travels almost as much as far as I do almost daily to get to BosLab and work there. But a lot of the busy work she does, like a community outreach event where we need to advertise, and then she'll spend hours making a poster or a few posters to advertise for that."[321]

Wendy's experience as an executive director is not unique. In a set of field notes, I deliberately reference how Lisa must "wear many hats through the weekend", which resulted in my observation that BUGSS members were reluctant to approach her to troubleshoot issues to minimize their burden on her.[322]

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[321] Lim, Interview with Anat.
[322] Lim, "Field Notes 035 – Inner Harbor Project (2016 Samples PCR)," June 29, 2019.

Second, community labs are spaces that are trying to democratize the life sciences. Part of the goal behind democratizing biology is to allow members to do projects that reflect their personal interests and passions. Leticia at Genspace expresses this eloquently as she discusses the importance of self-starting on projects:

> "I think, sometimes, people would like someone to just be, like, 'Okay, can you just decide what we're doing?' And then, it's like, 'No, because then it's not a community goal. It's a staff member telling us what we're doing.' It actually has to come from you guys and, the thing is, I want these projects to both be self-driven and maybe no reliant on a staff member so the membership and the community can organize itself and really, you know, feel empowered in the space."[323]

Collaborative

In the drives chapter, the drive to engage in community-building and community-affirming activities was a significant motivation for founders, leaders, and members to start, join, and continue being involved in their community lab. This desire of community-building not only has to do with building a space where like-minded folks can build a science-loving community and convince others to join it – community-building also involves talking and collaborating with others on projects. The collaboration dataset found three ways that labs fostered collaborative efforts and

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[323] Lim, "Interview with Leticia".

environments. TJ at CCL discusses how he views collaboration in the lab in the context of community projects like Vegan Cheese and Open Insulin:

> "I want to make a biotech co-op. If It turns out that Vegan Cheese turns into a biotech co-op, then great. Open Insulin as well, yeah. Everyone's working together, that way we can specialize our jobs, but let's not have a structure to it. And I wonder what that world would look like, and how it would do."[324]

Community labs also foster an open and collaborative atmosphere by hosting events that bring people together over a common issue or purpose. Eric from BioCurious notes how he often witnessed people coming together and beginning open collaborations at the community lab after events or seminars:

> "So in this exploration, when you can get two people to sit down with the same disease or affliction and really talk about it and get scientists in the room, you can use the resources at one of our laboratories to create a cohort that gets together and talks about their disease. Interesting things might happen, because we've already seen interesting things happen at BioCurious with people coming together and making companies."[325]

This view of bringing outside and inside stakeholders involved in a project is particularly salient regarding projects like the Inner Harbor Project: a project involving not only BUGSS, but local academic institutions like the National Aquarium and the Institute for Marine and Environmental Technology.[326]

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[324] Lim, "Interview with TJ".
[325] Lim, "Interview with Eric".
[326] "Welcome to Barcoding the Harbor!" *BUGSS*, https://bugssonline.org/group-projects/barcoding-the-harbor/. Accessed March 24, 2021.

Finally, these spaces deliberately foster a space where different disciplines can come together, talk, and encourage collaboration that allows people to expand their horizons and think beyond their own expertise. Wendy from BosLab captures this essence of collaboration in community lab spaces while talking about a bioprinting project:

> "I look at our do-it-yourself biology community bioprinting group. And I watch them try to develop a project and I'm watching material engineers talk to microbiologists talk to general construction contractors. You know? I mean, when would you ever see that? And they just think so it forces everyone to think outside of their own box. And with everyone's unique perspective and background, I think it's the power of these community labs to bring the community together to solve a problem."[327]

Gaining Funds

Community labs have four main ways of gaining funds. The first way is through community lab membership fees. In an ideal world, community labs would be free and live up fully to the vision of making the life sciences accessible to all. However, these spaces cost money to run, so community labs must find ways to gain funds to keep these spaces open.

There are also three different types of members in U.S. community lab spaces. Some members are paying members that pay a monthly fee, which range from $25/mo. -

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[327] Lim, Interview with Wendy.

$200/mo. at the community labs that this dissertation researched, to their community lab for full access to the lab, including access to shared materials, reagents, and equipment.[328] In the case of spaces like BUGSS and Biotech without Borders, full members can also gain 24-hour access to the space after a probationary period to determine whether a person can be trusted to be safe and responsible.[329] There are also bioincubator and entrepreneur-tier memberships at labs like BUGSS and BioCurious that cost more than typical memberships, but come with perks like dedicated wetlab bench space and office space to store documents and administrative paperwork.[330]

Other members pay a reduced membership per month in return for restricted access to the community lab – in a space like BosLab, these individuals may be able to participate in community projects, but they would not have access to the lab space for personal projects or projects outside of the specific community project they are working on.[331] Finally, some members are entirely volunteer members – these are individuals who may be involved in a community project and, with the lab leaderships' permission, are allowed to participate without paying a monthly fee for access and materials.[332] Table 16 on the following page provides a summary of the different types of memberships options at each community lab:

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328 For examples, see "What You Can Do," *BosLab*, https://www.boslab.org/participate. Accessed March 24, 2021; "Membership," *BUGSS*, https://bugssonline.org/membership/. Accessed March 24, 2021; "Join," *Counter Culture Labs*, https://www.counterculturelabs.org/join.html. Accessed March 24, 2021; and "Lab Membership," *Biotech without Borders*, http://www.biotechwithoutborders.org/lab-memberships. Accessed March 24, 2021.
329 Lim, "Interview with Lisa" and Lim, "Interview with Ellen".
330 Lim, "Interview with Maria" and Lim, "Interview with Lisa.
331 Lim, "Interview with Anat".
332 Lim, "Interview with Lisa".

Table 16 – Members: Volunteers vs. Reduced Cost Memberships vs. Full Memberships

Community Labs	Volunteer Members	Reduced Cost Membership	Membership
BUGSS	Y	Y	Y
BioCurious	Y	Y	Y
Biologik	Y	Y	Y
Biotech without Borders	Y	Y	Y
BosLab	Y	Y	Y
CCL	Y	Y	Y
Genspace	Y	Y	Y
Indie Lab	Y	N	N
Open Bio Labs	N	N	Y

The second main way that community labs gain funds is through paid classes and events. Before COVID-19, many of these events were hosted at the community lab. Depending on the event type, how long it runs, and what types of materials are used or required, event attendance costs in this dissertation research ranged from free events to a computer code-learning class that cost $30 for a 3-hour session at Biotech without Borders.[333]

The third way that community labs typically gain funds is through donations. This type of funding could take several different forms. Some organizations, like Open Bio Labs, passed around a donation bucket, or even a donation boot, during events to get some funds.[334] Others like BioCurious, CCL, and Open Bio Labs have used

[333] For examples, see Lim, Field Notes 018 – 019, 026, 033 – 034, 050, 066, and 078 – 080.
[334] Lim, "Interview with James".

crowdsourcing mechanisms like GoFundMe, Kickstarter, and Experiment.com to do everything from building up funding to rent and start a space to using the donations for specific projects and activities.[335] Some receive large private donations through fundraising events and direct outreach to funders and philanthropists.

Finally, the fourth way that community labs try to gain funds is through grants. This typically involves a single person or a team of individuals at a community lab researching and writing grant applications.[336] While grants have been acquired in the past from foundations to pay for things like paying to hire staff members to operate as salaried members of a community lab, this type of funding typically goes towards specific education programs like immersive science experiences for schoolchildren, or towards specific projects like a project that focuses on environmental assessment like the Inner Harbor Project.[337]

Funding Expenditures

This research found three main ways that community labs expend funds. The most frequently referenced expenditure was to purchase necessary lab materials and equipment to allow wetlab work in the space. Community labs acquire equipment through several different avenues. One way is through online auction sites like eBay,

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[335] For examples, see Lim, Field Notes 019, 026, 033 – 034, 037, 050, 066, and 078 – 080.
[336] See Lim, “Interview with Sairah,”; Lim, “Interview with Lisa,”; Lim, “Interview with Tom,”; Lim, “Interview with Deb,”; Lim, “Interview with Tim,”; Lim, “Interview with Dan,”; and Lim, “Interview with James”.
[337] For examples, see Lim, “Interview with Lisa,”; Lim, “Interview with Deb”; Lim, “Interview with Tom”; Lim, “Interview with Dan,”; and Lim, “Interview with Beth”.

which houses lots of second-hand equipment.[338] In certain regions like the East Bay Area and in areas around upstate NY, Long Island, and Cambridge, MA, there are also surplus depots where people can go in person to browse second-hand lab equipment for purchase.[339] People also could get equipment cheaply or even for free if they had the right connections. Tom from BUGSS recalled how his professional network helped him get equipment he needed for his community lab:

> "So there was a professor who was retiring at UMBC, and he said, 'Hey, come into the lab and take what…' I mean, most of the big equipment was gone, but, you know, there was a lot of little things that we use. There was a company that was going out of business, I think it was called Nabbie Therapeutics or something like that, and somehow, we got in touch with them, and they sold us a lot of equipment for pennies on the dollar. So I think we spent about $10,000 - $12,000 or something like that and got, you know, power supplies, pipettes, and biosafety cabinets, and a minus 70 freezer, and you know, on and on and on."[340]

In terms of reagents, community labs typically either got reagents through donations or direct purchase from life sciences reagent production companies like Carolina Bioscience.[341]

Second, community labs have basic fixed costs for rent and utilities for the space. These costs can be quite significant. In terms of rent, the values wildly fluctuated despite

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[338] Lim, "Field Notes 057 – Pittsburgh Biohacking Space Start-Up Conversation," September 13, 2019.
[339] See Lim, "Field Notes 068," September 28, 2019; "Field Notes 076 – Coffee with Danny," February 08, 2020; and Lim, "Interview with Tim".
[340] Lim, "Interview with Tom".
[341] For examples, see Lim, "Interview with Lisa,"; Lim, "Interview with Danny,"; Lim, "Interview with Lada,"; and Lim, "Interview with Rolf".

most of these spaces being in urban, technologically-developed areas – monthly rents ranged from $600 at Genspace in its early years to $11,000/mo. for the current space that BioCurious occupies.[342] While no ranges were provided for the cost of utilities at community labs, they were also mentioned as an expenditure on the minds of community lab members and leadership.[343]

Finally, some community labs expend funds on paid staff. In the 9 U.S. community labs that I researched for this dissertation, each lab contained a combination of leaders and members. For all the community labs except Genspace and Open Bio Labs, leaders are all volunteers – no one is paid to do professional work specifically related to the administrative operations of the lab. Genspace has a combination of volunteer leaders, as well as paid professional leader positions. These paid positions at Genspace included 1) two co-director positions that oversaw everything from fundraising and development to lab oversight and course design; 2) a community lead that manages the day-to-day activities such as lab management, coordinating meetings, and organizing the space; and 3) a communication director.[344] In the case of Open Bio Labs, their community lab busines model was to eventually gain enough revenue for leadership to earn a salary, but the lab never managed to get profitable enough for this to occur.[345] Table 17 on the following page provides a summary of the volunteer versus salaried membership and leadership at each community lab:

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[342] See "Field Notes 062 – Preliminary Visit to BioCurious," September 16, 2019 and Lim, "Interview with Ellen".
[343] For examples, see Lim, "Interview with Wendy,"; Lim, "Interview with Bill;", Lim, "Interview with Peter,"; Lim, "Interview with Ryan;", Lim, "Interview with Eve,"; and Lim, Interview with Ellen".
[344] See Lim, "Interview with Beth,"; Lim, "Interview with Angela,"; and Lim, "Interview with Leticia".
[345] See Lim, "Interview with James," and Lim, "Interview with Shaun".

Table 17 – Community Lab Members and Leaders – Volunteer vs. Paid

Community Labs	Volunteer Members	Volunteer Leadership	Salaried Leadership
BUGSS	Y	Y	N
BioCurious	Y	Y	N
Biologik	Y	Y	N
Biotech without Borders	Y	Y	N
BosLab	Y	Y	N
CCL	Y	Y	N
Genspace	Y	Y	Y
Indie Lab	Y	Y	N
Open Bio Labs	Y	Y	N

Funding Obstacles

This research found that community labs face 4 main obstacles when it comes to funding. The first is that these spaces, even a space like Genspace that is financially supported to the point where it can hire staff, run on small budgets, and therefore depend on equipment and reagent donations to keep the lab running.[346] The data indicates that this is driven by a tension between the desire to live true to the ideology of democratizing technology and the need to generate income. Wendy highlighted this tension while discussing how current membership fees at BosLab are $50/mo.:

> "I think, like all community labs, we struggle to find what is a sustainable business model. I think in the past, BosLab has been 100% dependent on the

[346] Lim, "Interview with Angela".

> membership, and our membership fees are currently $50/mo. So we, in addition to Sound.Bio, we might actually be some of the cheapest membership costs, but it's questionable whether that will stay like that. We're like to, because we think that a barrier for some people to enter our group and to really use the lab as they'd like to is that $50 membership."[347]

The second is most of these spaces are run by volunteers. While using volunteers to do things like grant-writing keep costs down, it also introduces issues when other priorities come up in the lives of people and, therefore, are unable to complete grant-writing for a crucial source of funding. When Lisa took over as the Executive Director of BUGSS following Tom, she found herself in a quandary concerning grant-writing and making sure BUGSS didn't lose money over iGEM:

> "I think one of the big ones [sacrifices] this past year was iGEM. Every year up until 2019, we've been able to send everybody to the Jamboree who wanted to go. This was the first we had to send only four students, and we knew more students wanted to go. And it broke my heart that there were students we couldn't send. The difference this year has been that since I've moved to Executive Director, nobody has replaced me in the role of Secretary, which is really sad. Certainly, no one has replaced me for the grant-writing, and so I haven't been able to do both the Executive Director with all the kind of day-to-day paying bills stuff and grant writing."[348]

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[347] Lim, "Interview with Wendy".
[348] Lim, "Interview with Lisa."

Third, while there are examples of community labs being funded through crowdsourcing mechanisms, many starting community labs are funded directly by the founder. Even at discounted rates for materials and equipment, these costs can add up and generate stress for the founder as funds run low. In a conversation that I had with Tom from BUGSS, I captured in my observational field notes how funding and managing BUGSS gave him lots of stress:

> "When I asked Tom what some of the difficulties with running a lab was, Tom heavily referenced a recent experience of his. He had recently retired and actually had considered closing BUGSS down during this time. He wanted to spend more time for himself and his family, and he found the financial stress of maintaining the BUGSS space was contributing to him burning out: losing his passion for science and for community science. He described the financial burden as akin to feeling like having your first paid job and stressing about making sure all your rent and bills are paid from month-to-month."[349]

Finally, even if grant-funding is available to these community labs, the grants are typically tied to some activity or project. While this allows community labs to do interesting projects and do science outreach, many of these grants do not allow the grant to be used for things that may be beneficial for community labs, like other expenses. Ryan at BUGSS highlights how the inflexibility of grants creates issues in community labs:

[349] Lim, "Field Notes 007 – Conversation with Tom," April 13, 2019.

> "Our initial grant that funded the lab manager position, I think that was a real boost in a lot of ways, but that grant was also designed to taper off over time, and we found it actually quite challenging to replace those costs. It's really hard to fundraise for basic operating expenses. Nobody wants to volunteer to pay your power bill or your rent. That's just not a sexy thing. It's easier to get funding to fund some sort of special project or initiative, but the operations costs is really hard."[350]

Biorisk Threat Evaluation of U.S. Community Labs through Design Data

Overview – Inner Harbor Project

The Inner Harbor Project, also known as the Barcoding the Inner Harbor Project, is a collaboration between BUGSS and several environmentally inclined academic institutions such as the National Aquarium and the Institute for Marine and Environmental Technology. It is sponsored through a grant from the Chesapeake Bay Trust: a non-profit, grant-making organization whose focus is to improve the watersheds of the Chesapeake Bay area.[351]

This collaboration came about following a multi-week course hosted at BUGSS entitled "Analyzing the Inner Harbor". One of the scientists from IMET, Tsetso, came to BUGSS and taught a series of classes on acquiring environmental samples, extracting,

[350] Lim, "Interview with Ryan".
[351] "Barcoding the Inner Harbor," *BUGSS*, https://bugssonline.org/group-projects/barcoding-the-harbor/barcoding-the-inner-harbor-dna-analysis/. Accessed March 27, 2021.

purifying and amplifying the DNA, then running computer analyses on the sample sequence data to understand what may be present in the water at a genomic level.[352]

Following the conclusion of the Analyzing the Inner Harbor series of courses on April 13, 2019, an attendee of the class named Sairah asked Executive Director Lisa Scheifele if there was meant to be any follow-through once the course was completed – she wanted to see if BUGSS could find a way to participate and help in the project. After some discussion between myself, Lisa, Sairah, and another member named Andy, we decided to see how we could contribute to the workflow of the project.

Over the course of several months, BUGSS became an integral part of the sample preparation, processing, and analysis portions of the project. A visualization of the workflow, and where BUGSS is involved, is available in Figure 1 below:

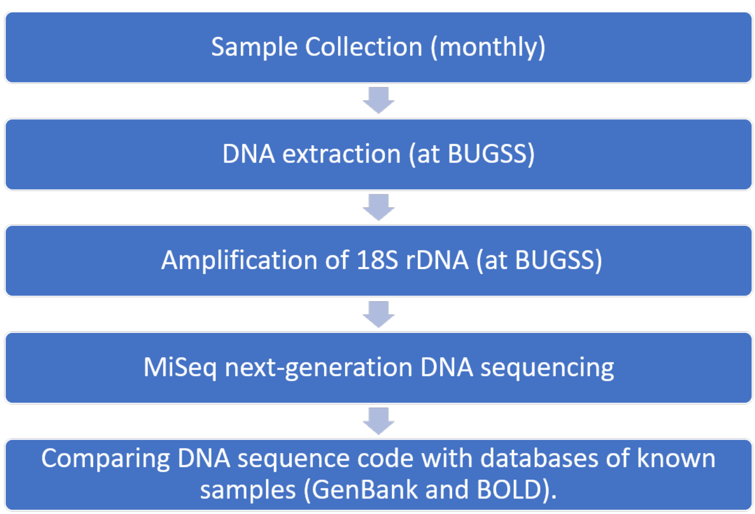

Figure 1: Graphic Representation of Project Workflow

[352] See Lim, "Field Notes 002 – Analyzing the Inner Harbor, Hosted by BUGSS," April 06, 2019 and Lim, "Field Notes – Analyzing the Inner Harbor (Third Meeting)," April 13, 2019.

This project officially began on April 27, 2019 and has continued to the present.[353] The current state of this project, in terms of sample preparation and processing, is on hold given the COVID-19 pandemic, which has caused the BUGSS space to physically close for the time being. However, the existing data is currently being turned into report titled *Community Science Census of Biodiversity in an Urban Estuary*.[354]

DIYBio Community Lab Projects – Indications of Collaboration and Trust

At the start of the project, 3 out of the 5 BUGSS members were biologists at various levels of proficiency: 2 were PhD-level biologists with backgrounds in biotech and molecular biology, and 1 had recently graduated with their undergraduate degree in biology. Andy and I the two BUGSS members with little to no background in the life sciences, let alone working in a lab.[355]

What this meant was that roughly 40% of the group could not contribute to the sample preparation, processing, and analysis despite our desire to engage in the group. Therefore, Andy and I tended to mostly observe what the peoples with lab skills would do. For example, during one of the first days of sample preparation, I observed Tom and Sairah working through analyzing samples related to the project in the lab. These were samples that the sequencing company BUGSS used, called Resphaera Biosense, had indicated showed no results, meaning no DNA was present in the samples.

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[353] Lim, "Field Notes 011 – Analyzing the Inner Harbor Continuation by BUGSS," April 27, 2019.
[354] Lim, Personal E-mail Correspondence, March 26, 2021.
[355] Lim, "Field Notes 020 – Analyzing the Inner Harbor (Gel Electrophoresis 2017) at BUGSS," May 18, 2019.

To confirm that no DNA was present in the samples, Sairah and Tom used a NanoDrop spectrometer – a device that measures light wavelengths that are absorbed by a sample. The principle here is that if the Nanodrop spectrometer read absorptions of particular wavelengths, it would indicate that DNA was present in the sample.

While I observed and the samples were analyzed, conversation tended to be casual, with discussions including pets, how people ended up in the East Coast, as well as background and education. As I began to repeatedly see how they implemented their protocol, I eventually volunteered to help in the process by passing samples to Tom. As I went through the process of the protocol, we continued conversing, but Tom or Sairah would occasionally provide suggestions on how I might better use the pipette, how important it was to maintain steady hands throughout the process and making sure I properly wiped down the spectrometer between samples.[356]

This type of interaction, where experts would convince individuals to try learning new practices or knowledge in small-group settings, was a common occurrence in the BUGSS space.[357] It did not just occur between BUGSS members, either. On occasion, our collaborators from IMET would drop by the lab to drop off samples, as well as providing important materials like distilled water from their lab and blue crab DNA to use as a positive control when we ran certain protocols.

Through a series of classes and instruction over time, I had learned how to create agarose gels – the medium that samples are placed in as a part of a protocol known as gel

[356] Lim, "Field Notes 016 – Analyzing the Inner Harbor (Sample + PCR) at BUGSS," May 11, 2019.
[357] For examples, see Lim, Field Notes 002, 008, 011, 016, 020, 028, 031 – 032, 035, 038 – 039, 042, 046, 049, 067, 070, 075, and 079.

electrophoresis.[358] Given my seeming proficiency to create gels that did not break, I typically had the task of creating gels for the project. On July 20, 2019, one of the scientists from IMET, Eric, came to drop off some materials for the lab. Eric and I struck up a conversation, including his asking me what I was working on for the project that day. When I mentioned that I was making a gel, but how the protocol had failed the previous week, he was able to offer some suggestions on how to improve our protocol.

Further, while he was observing me making a gel, Eric suggested and demonstrated a shortcut to help cool my gel down faster to cut down on the protocol time. Typically, I would fill a flask with the appropriate reagents and agarose powder, microwave gently to make sure all the agarose powder was fully dissolved into the reagents, and then would have to wait 15 – 20 minutes for it cool sufficiently to pour into a mold. Eric demonstrated how I could fill a large beaker with cool water and use it as a heat sink to drain away the heat from my flask. This shortcut not only worked well, but it ended up shaving 13 – 18 minutes off my cooldown time.[359]

Collaboration across IMET and BUGSS was also critical for addressing a contamination issue that was generating issues for the project. Early in the start of the project, the group began to run into potential contamination issues. It started with the positive presence of DNA in the negative control for the gel electrophoresis.[360] Subsequent weeks showed other potential issues cropping up despite our attempts to fix

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[358] Gel electrophoresis is a technique that is used to separate DNA fragments according to size by running an electrical current through an agarose gel that houses the samples of interest. Larger fragments travel down the gel slower, while smaller fragments travel down the gel faster.
[359] Lim, "Field Notes – Inner Harbor Project – Abbreviated Gel Making," July 20, 2019.
[360] Lim, "Field Notes – Analyzing the Inner Harbor (Gel Electrophoresis 2017)," May 18, 2019.

the contamination issue by using unopened bottles of water, getting more fresh blue crab samples from IMET for the positive control, and trying to eliminate other potential contamination possibilities by adding strict environmental sterilization protocols.[361] Only after months of troubleshooting together, running multiple gels to check all reagents and samples for potential contamination, and most of the pipettes in the lab did the group collaboratively find out that a pipette had likely been contaminated by having its pipette tip pushed in too far, causing the barrel to be contaminated. Subsequently, this pipette then ended up contaminating other reagents in the lab.[362]

While the group collaborated in an open and trusting fashion across the two years this study has been going on, one major issue that this group faced was maintaining a stable cohort of project members. As the project continued onwards, we gathered 3 new people that were interested in participating in the project: a high school student named Madeline, and two Baltimoreans named Danielle and Afeisha. As time passed on the project, there were tendencies where the newer members, who had not been there from the beginning, would drop out for 2 – 4 weeks at a time for professional and personal reasons. I would also have to take time to head out for 1 – 2 weeks on occasion given my dissertation research. However, the most impactful long-term absence was when Tom Burkett went on a retirement vacation for 6 months. The loss of his expertise over this long period of time had two main effects. First, it dampened our confidence somewhat by not having a PhD biologist readily available. Second, it took a significant amount of time

[361] For examples, see Lim, Field Notes 020, 028, 035, 038, 042, 046, 067, and 070.
[362] Group e-mail correspondence with Andy, November 15, 2019.

to catch Tom back up on what had occurred, which impacted the pace of the research project.[363]

Therefore, U.S. DIYBiology labs show evidence of engaging in complex scientific projects with a collaborative and collegial attitude. The casual conversation environment helps cultivate a close-knit community of members that are working on a friendly basis towards a shared end goal. Further, experts are more than happy to share their knowledge and expertise with amateurs, which indicates trust and a desire to provide expertise and assistance to others. Finally, there is evidence that indicates members across different stages are willing to converse and learn from each other to do everything from finding better ways to do particular protocols to troubleshooting contamination issues over the course of nearly half a year.

DIYBio Community Lab Projects – Indications of Leadership Limitations

In the Barcoding the Inner Harbor Project, Lisa played a significant managerial role. She was initially the one that helped coordinate activities between BUGSS, IMET, and the National Aquarium.[364] In addition, she was the one that the BUGSS group would need to go to if we had questions about reagents, protocols, or other science-related issues.[365] This dynamic was further exacerbated when Tom Burkett, who was the former

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[363] For examples, see Lim, Field Notes 002, 008, 011, 016, 020, 028, 031 – 032, 035, 038 – 039, 042, 046, 049, 067, 070, 075, and 079.
[364] See Lim, Field Notes 002 and 008.
[365] Lim, "Field Notes 038"

director and did much of the complex elements of the protocol, left for an extended vacation after he retired.[366]

As she could, Lisa was engaged with the project. She made sure to ask questions about whether there was anything that the group needed before it began its activities. She also made sure, as she could, to be available to answer questions or provide answers to technical questions when Tom was not around.

However, the project could not be Lisa's top priority. Typically, BUGSS would run multiple events simultaneously which she would have to oversee. For example, April 27, 2019, involved three events happening in tandem: the Barcoding the Inner Harbor Project, an iGEM mentorship event, as well as a volunteer orientation event.[367]

This dynamic was well-understood and internalized in the group running the project. Lisa provided every indication that if we required her help, we should feel comfortable to approach her, even if she was busy with something else. However, the group of us, particularly Andy, Sairah, and I, felt uncomfortable approaching Lisa at times when we knew she was exceptionally busy. This is when the group developed a policy where Lisa was not to be interrupted except during situations where we had exhausted all possibilities in resolving an issue.[368]

There were also situations where Lisa could not be present in the lab due to an outreach event. During these times, the group would often fill in as proxy leaders, as we were all responsible adults. On July 20, 2019, while Lisa was doing outreach for BUGSS

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[366] Lim, "Field Notes 028 – Analyzing the Inner Harbor (Gel Run)," June 8, 2019.
[367] See Lim, Field Notes 011 – 013.
[368] Lim, "Field Notes 035 – Inner Harbor Project (2016 Samples PCR)," June 29, 2019.

at a local Baltimore event called Artscape, the electrical system in the lab overloaded, resulting in the group pivoting from research to addressing the electrical issue. Over the course of an hour, we were able to jerry-rig a set-up using extension cords and some reorganizing to make sure that the refrigerators and freezers were all properly powered, and the iGEM students could continue doing their research with their charging laptops and access to Wi-Fi. We had notified Lisa about the issue and she thanked us for addressing the issue.[369]

There were also situations where Lisa had difficulty in supplying the group with the tools and information we felt we needed to make progress on the project. One example was when we had run out of a nucleic acid stain we normally used called "GelRed" – it binds to DNA and causes it to glow under UV light. When we asked if there was any more GelRed left through text, she indicated that we could use a substitute she had called Gel Green that she had left by the lab scale. She had not been able to order any following weekday classes where the students used all the GelRed in the lab. She provided us instructions as well, but we noticed that the expiration date had passed. When we followed her instructions and did the gel electrophoresis protocol, we found that the process failed.[370]

Therefore, the data indicates that Lisa did display some characteristics that made for a good science manager. She made herself available as she could, and she operated in a way that allowed our group to work in a cohesive and collaborative manner. However,

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[369] Lim, "Field Notes 039 – Inner Harbor Project (Abbreviated Gel-Making)," July 20, 2019.
[370] Lim, "Field Notes 038 – Inner Harbor Project – Large Gel Electrophoresis," July 13, 2019.

given her multitude of duties and responsibilities, there were barriers to transparency brought on by our group's desire to be considerate of her time and attention. In addition, there were times that Lisa was stretched so thin that she faced difficulties in keeping the project sourced with necessary reagents and materials to conduct research.

DIYBio Community Lab Projects – Indications of Financial Limitations

BUGSS is a community lab whose members and leaders have expressed significant financial limitations. These financial limitations have considerable impacts on how science is performed in this space in two main ways. First, the financial limitations affect the community lab's ability to purchase and access equipment for scientific research. A significant obstacle that created issues for the project was when the polymerase chain reaction (PCR) machines that we used to amplify the purified sample data all began to stop functioning in the lab. User issues for these machines included button errors, unprogrammed pauses that caused the samples to not be fully amplified, and even having situations where the PCR machines would not turn on.[371] Therefore, as a stopgap while Lisa tried to find the money to purchase a large new PCR machine, we had to use a loaned mini-PCR machine from another BUGSS member. While this was generous of the individual, this significantly slowed our workflow as the PCR machines we used before could process 96 samples at once: the borrowed mini-PCR could only handle 8 samples at one time.[372]

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[371] For examples, see Lim, Field Notes 016, 035,
[372] Lim, "Interview with Andy".

Second, even reagents and materials could be difficult to get a hold of. Issues like the Gel Green issue discussed in the previous section are not atypical. Rather, they are the norm. Lisa noted in her interview that BUGSS was a financially sleek organization, which causes issues with how people can operate and contribute in the lab:

> "I think we do a really good job. "We're a pretty sleek organization. We don't spend a whole lot more than what we need to. So, you know, our big costs are really things like rent, and electricity, and all of that kind of stuff. Even for supplies, we're pretty tight with that. We get a lot of donations, which is great. We look out for donations, things like that."[373]

Therefore, the data indicates that financial limitations have a disruptive and delaying effect on complex scientific tasks in community labs. As equipment failures occur, particularly for critical lab equipment like PCR machines, it can significantly slow and impact the progress of complex scientific projects like Barcoding the Inner Harbor. The same holds true for reagents and materials which, again, community labs might have difficult purchasing as needed due to their financial limitations.

Conclusion

The biorisk community has operated under a problematic assumption that is not based on fact: that access to technical equipment and information alone are sufficient to successfully complete complex scientific tasks and projects. The existing literature already shows that this assumption does not hold true, as complex scientific ventures like

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[373] Lim, "Interview with Lisa".

the Open Insulin and Glowing Plant projects have not succeeded despite adequate funding and access to the necessary equipment and information to achieve successful scientific outcomes. Therefore, insights from the STS literature have shed light on how capable community labs may be at handling complex scientific tasks and projects by looking at the design data that I gathered in this dissertation research. This chapter concludes with some brief implications and limitations on the biorisk threat assessment using U.S. community lab drive data.

Implications

In the case of U.S. DIYBio community lab drives, the biorisk threats associated with these spaces are a mixed bag. In terms of factors that make it so that complex scientific tasks are more likely to be achieved, U.S. community labs have cultivated the right kind of culture to ease the development, use, and transfer of tacit knowledge and expertise. These spaces are casual, friendly, and experts are more than happy to teach others what they know. Furthermore, individuals are willingly to come together organically to accomplish projects, and even work together across different stages of the scientific protocol to help make the process more efficient and help troubleshoot problems. Further, the design data does indicate that community labs may have leadership that can help cultivate this type of ideal space for completing complex scientific tasks.

However, the data also indicates that there are also elements of community labs that could create significant issues and delays in successfully completing a scientific project. Leadership in community lab spaces are forced to carry significant amounts of duties and responsibilities that serve as an obstacle for leadership to be fully aware of what is going on with a project. Furthermore, the lack of stable participants at times can generate significant delays in research progress – this is particularly true if the individual is one whose expertise is very much needed or appreciated for the success of the project. Furthermore, community labs suffer from significant limitations in their budgets, which results in situations where projects may not have access to the necessary equipment and reagents to make progress.

Therefore, at this current moment in time, it appears that U.S. DIYBio community labs may have some of the characteristics that enable the completion of a complex scientific project, but may lack others. That said, it is reasonable to assume that community labs are slowly improving on their ability to conduct good science given the emergent success of the Barcoding the Inner Harbor project, which is culminating in a scientific report and associated with academic institutions.

Limitations

This analysis has three main limitations. There are questions about being able to generalize the findings from this data to other groups within the DIYBio community. It is also likely difficult to generalize this data to community labs in other regions due to how different regions operate with different laws and likely have different interests in activities. Therefore, this analysis is only truly applicable to DIYBiology community labs based in the U.S. Furthermore, the case study used to highlight the design data related to U.S. DIYBio labs was BUGSS: the community lab that I spent the most amount of time at.

Therefore, the ability to generalize the experiences at BUGSS to other community lab experiences is limited.

Second, it is important to note that the STS literature that I used refers to complex scientific projects and tasks that are not perfectly analogous to those within the DIYBio context. For example, Ben Ouagrham-Gormley's studies of socio-organizational components affecting the development of complex biological weapons systems and Hoyt's studies on the development of vaccines are significantly more complex than the project I used as a case study – one where people retrieved, prepared, processed, and analyzed samples.

Third, the design data I gathered for this dissertation research was entirely qualitative and acquired through personal on-site visits for observational data, and virtual interviews for interview data. My ability to gather this data was enabled largely through my prior interactions and relationship-building with the community 3 years prior to the start of my dissertation research. The large dependence on personal experiences and memories, particularly for the interview data, does introduce the issue of self-reported data bias.

CHAPTER SIX – THE DEGREE OF DEMOCRATIZATION THAT US DIYBIO COMMUNITY LABS REPRESENT AND THEIR BIORISK THREAT IMPLICATIONS

Introduction

Chapter 6 focuses on analyzing the biorisk narrative's assumption that the life sciences have been fully democratized – anyone can now access the equipment, skills, materials, and information necessary to do any type of science they wish. This chapter will begin by providing a brief overview of the existing literature that exists at the intersection of STS and information and communications technology (ICT) to highlight the importance of two categories of accessibility that should be considered in the democratization discussion. The first facet of accessibility considered in this dissertation is market accessibility – the degree to which a drive exists to increase the accessibility of equipment, materials, tools, reagents, and other goods associated with the life sciences by decreasing the costs associated with accessing such items outside of academia, industry, and government. The second facet of accessibility considered in this dissertation is information accessibility – the degree to which a drive exists to make information obtainable and collaboration possible across individuals and communities that fall outside traditional life sciences institutions like academia, industry, and government. This chapter then provides an overview of the degree of democratization that U.S. DIYBio community labs represents concerning the life sciences.

I arrived at 4 main findings from the degree of democratization data. First, community labs were known for generating their own equipment, but this equipment had varying results – for those that do work, they are not necessarily cheap or easy to access. Second, the dependence of community labs on second-hand equipment exposes them to financial and reliability issues. Third, amateur biologists can learn to navigate and find good resources to use and build their knowledge from, but there is a significant learning curve – even with the help of biologists in their community lab space, amateurs must learn to sift good information from all the questionable sources available online. Finally, the geographically decentralized nature of DIYBio creates unexpected barriers in sharing information across the community.

Finally, this section concludes with the implications and limitations of these findings. To a certain extent, the biorisk community is correct – increased access to equipment, materials, and information through platforms like the internet does allow a broader community of enthusiasts and practitioners to take part in the life sciences. However, just because the DIYBiology movement emerged does not mean that the life sciences have been fully democratized. Rather, the degree of democratization data in this dissertation shows how significant financial, tacit knowledge, and organizational barriers act as obstacles to broader democratization. Therefore, despite limitations associated with sampling, and potential bias and observer effects, this analysis concludes that the biorisk assumption that U.S. DIYBio community labs are indicative of the phenomenon that biology is fully democratized is erroneous and should be reconsidered.

The Biorisk Perspective – Everyone Can Access Life Sciences Equipment and Information

In 2021, it is unfathomable to think about a world without the internet – that decentralized global system that helps interconnect our computer networks and devices. Particularly in an era of COVID-19, it is impossible to imagine not having the internet as a source of entertainment, a means for communicating information and thoughts with the world, and a virtual proxy for our social and professional lives.

For the biorisk community, however, the internet has come to represent a dual-use technology: a technology which may be used towards good or malevolent ends. One capability the internet allows is the rapid and broad dissemination of information – with a good internet connection and a network-connected device, individuals can easily access the vast stores of information currently contained in various servers around the world. This capability has clear benefits – for example, SARS-CoV-2's entire genome was published online within days and accessible to scientists around the world.[374] However, biorisk experts are concerned that unadulterated access to research through the internet raises red flags since there may also be those that seek to use such access towards malevolent ends.[375]

Therefore, the emergence of the DIYBio community is particularly concerning for the biorisk community. Its emergence corresponds with the growing utility of the internet, as well as the dramatically falling costs associated with life sciences equipment

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[374] Ian Le Guillou, "Covid-19: How Unprecedented Data Sharing Has Led to Faster-Than-Ever Outbreak Research," *Horizon*, March 23, 2020, https://horizon-magazine.eu/article/covid-19-how-unprecedented-data-sharing-has-led-faster-ever-outbreak-research.html. Accessed March 27, 2021.
[375] Vogel, "Framing Biosecurity,": 46.

and reagents.[376] As more of these began opening in the mid 2010's onward, particularly in Global South regions like Africa and Southeast Asia, the biorisk community assumes that life sciences equipment, tools, and information are fully accessible to everyone.[377]

To test this assumption, one factor that needs to be explored is the degree to which democratization of the life sciences have occurred at present. In the academic, biorisk, and DIYBio literatures, democratization is the result of varying degrees of access – as something becomes more democratized, it is easier to access, and vice versa.[378] In the context of DIYBio community labs, democratization refers to increasing access to a broader audience that can now participate in the life sciences – those that exist outside of traditional institutions like academia, industry, and government.[379]

This concept of access overlaps significantly with Harvard internet law professor and expert Jonathan Zittrain's concept of "generativity" – the degree to which a technology facilitates the individual use and communal distribution of a technology and

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[376] Grushkin et al, *Seven Myths and Realities*.
[377] Kolodziejczyk, "Do-It-Yourself Biology Shows Safety Risks".
[378] For examples, see Pippa Norris, *Digital Divide: Civic Engagement, Information Poverty, and the Internet Worldwide,* Cambridge, UK: Cambridge University Press, 2001; Deborah L. Wheeler, "Empowering Publics: Information Technology and Democratization in the Arab World – Lessons from Internet Cafes and Beyond," *Oxford Internet Institute* 11 (2006): 1 – 18; J.B. Holbrook, "Open Science, Open Access, and the Democratization of Knowledge," *Issues in Science and Technology* 35, no. 3 (2019): 26 – 28; Jeremy Hunsinger and Andrew Schrock, "The Democratization of Hacking and Making," *New Media and Society* 18, no.4 (2016): 535 – 538; Harrison W. Inefuku, "Globalization, Open Access, and the Democratization of Knowledge," *Educause Review* 54, no. 4 (2017): 62 – 63; and Jonathan Zittrain, "The Generative Internet," *Harvard Law Review* 1974 (2006): 1975 – 2040.
[379] For examples, see Morgan Meyer, "Domesticating and Democratizing Science: A Geography of Do-It-Yourself Biology," Working Paper 13-MS-04 for the Interdisciplinary Institute for Innovation (2013): 1 – 22; Jozef Keulartz and Henk van den Belt, "DIY-Bio – Economic, Epistemological, and Ethical Implications and Ambivalences," *Life Sciences, Society, and Policy* 12, no. 7 (2016): https://doi.org/10.1186/s40504-016-0039-1; Barba, "We Are Biohackers," 2 – 26; Seyfried et al., "European Do-It-Yourself (DIY) Biology,": 548 – 551; and Gigi Kwik Gronvall, "Synthetic Biology: Biosecurity and Biosafety Implications," in *Defense Against Biological Attacks*, edited by S. Singh and Jens Kuhn. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-03053-7_11.

its applications.[380] When placed under the scrutiny of Zittrain's generative technology model, the DIYBio movement can potentially be considered a form of a highly-generative, techno-social phenomenon. First, capacity for leveraging biotechnology is becoming easier in some dimensions due to the "de-skilling" in existing life sciences technologies. This de-skilling is limited by intangible barriers such as tacit knowledge and expertise barriers that amateurs would have to overcome.[381] However, there are developments in the DIYBio community that can be seen as de-skilling, such as pre-packaged kits from the ODIN to do limited gene-editing experiments, as well as the open-source automated pipetting machine developed in Genspace called OpenTrons.[382]

Second, the DIYBio community has shown a remarkable capability for repurposing existing technologies or creating low-cost alternatives for lab equipment.

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[380] Zittrain, "The Generative Internet,": 1978 – 1982.

[381] With amateur participants, it will be difficult to overcome the need for expert advice and the close oversight and trust necessary to effectively build, transfer, and use tacit knowledge – knowledge that is housed within a person, difficult to verbalize, not necessarily consciously-implemented, and is often fixed to a specific temporal and geographic context. For examples, see Vogel, *Phantom Menace or Looming Danger*, Loc 1291 – 1986; Iris Hunger, Jez Littlewood, Caitriona McLeish, Piers Millett, and Ralf Trapp, "Roundtable: The Future of Biothreat Governance," in *Biological Threats in the 21st Century*, London, UK: Imperial College Press, 2016, 431 – 450; Ben Ouagrham-Gormley, *Barriers to Bioweapons* (2014), 17 – 63; and Sonia Ben Ouagrham-Gormley and Kathleen M. Vogel, "The Social Context Shaping Bioweapons (Non)proliferation," *Biosecurity and Bioterrorism* 8, no. 1 (2010), 9 – 24; Sonia Ben Ouagrham-Gormley and Shannon R. Fye-Marnien. "Is CRISPR a security threat?". In *Defense Against Biological Attacks*, 233 - 251. Springer, Cham, 2019; Kathleen M. Vogel and Sonia Ben Ouagrham-Gormley, "Anticipating Emerging Biotechnology Threats: A Case Study of CRISPR," *Politics and the Life Sciences* 37, no. 2, 203 – 219; and Kendall Hoyt, *Long Shot: Vaccines for National Defense*, Cambridge, MA: Harvard University Press, 2012: Loc 529 – 858.

[381] See Hoyt, *Long Shot*, Loc 71 – 87; Ben Ouagrham-Gormley, *Barriers to Bioweapons* (2014), 17 – 24; and Vogel, *Phantom Menace or Looming Danger*, Loc 1925.

[382] For examples, see "DIY Bacterial Gen Engineering CRISPR Kit," *The ODIN*, https://www.the-odin.com/diy-crispr-kit/. Accessed March 14, 2021; "Bacterial CRISPR and Fluorescent Yeast Combo Kit," *The ODIN*, https://www.the-odin.com/bacterial-crispr-and-fluorescent-yeast-combo-kit/. Accessed March 14, 2021; "Meet the OT-2: Lab Automation has Never Been Easier," *OpenTrons*, https://opentrons.com/ot-2. Accessed March 14, 2021; and "New High-Precision Pipettes: Reliable Liquid Transfers from 1 – 1000 microliters," *OpenTrons*, https://opentrons.com/pipettes. Accessed March 14, 2021.

Articles and primers on the internet share how reversing the lens in a webcam can be used to create small microscopes, using the heat from one's own armpits can work as a makeshift incubator, and printing open-source parts and attaching them to a Dremel rotary tool can function as a makeshift centrifuge.[383]

Third, the emergence and rise of the DIYBio community implies that the life sciences are easy to master and implement. This perceived ease of mastery dovetails in the DIYBio context with two considerations. The first is that the life sciences are being researched and practice by amateurs outside of academic institutions. The second is how the emergence of DIYBio temporally and narratively corresponds with the rise of synthetic biology – an engineering approach to the life sciences. The goal of both movements is to make biology more accessible and easier to perform than ever.[384]

Fourth, the DIYBio movement would not be possible without recent developments which enable increased accessibility to tools, information, and materials. The generative nature of the internet, combined with diminishing costs in life sciences equipment, allow DIYBio members to gain access to tools, numerous resources of information, leveraging online platforms for financial crowdfunding, and practitioners both online and in-person willing to share their knowledge, experiences, and lessons-learned in doing personal and group projects in this context.

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[383] For examples, see Ledford, "Garage Biotech" and D'Haeseleer, "How to Set Up Your Own DIY Bio Lab".

[384] For examples, see Sophia Roosth, *Synthetic: How Life Got Made,* Chicago, IL: University of Chicago Press (2017): 127 – 144; Landrain et al., "Do-It-Yourself Biology,": 115 – 118; Gigi Kwik Gronvall, "Safety, Security, and Serving the Public Interest in Synthetic Biology," *Journal of Industrial Microbiology and Biotechnology* 45 (2018): 463 – 466; and Roth, "A Guide to DIYbio,".

Therefore, this dissertation takes advantage of this overlap and uses 2 components of accessibility to measure the degree of democratization in the case of DIYBio: the degree to which DIYBio represents a fully democratized outcome of life sciences technology and information. The first facet of accessibility considered in this dissertation is market accessibility – the degree to which a drive exists to increase the accessibility of equipment, materials, tools, reagents, and other goods associated with the life sciences by decreasing the costs associated with accessing such items outside of academia, industry, and government. The second facet of accessibility considered in this dissertation is information accessibility – the degree to which a drive exists to make information obtainable and collaboration possible across individuals and communities that fall outside traditional life sciences institutions like academia, industry, and government.

The Degree of Life Sciences Democratization

I obtained the degree of democratization data of community lab members through two means. First, I used interview data as each interview contained questions about how individuals found out life sciences information they were interested in, as well as how they did activities like purchase equipment and participate in projects. Second, I used on-site observational data to see, interact with, and personally experience what equipment and information is accessed, acquired, and used in these spaces. In total, there were 8 founders or co-founders of community labs who were interviewed in this study, along with 18 leaders and 18 participants.

Degree of Democratization

Market Accessibility

Historically, DIYBio members made a lot of their own equipment for their garage lab setup. In addition, instructions for this were readily available on the internet. Popular articles such as Heidi Ledford's "Life Hackers" article in *Nature*, as well as CCL co-founder Patrik D'haeseleer's article in the DIY-activity-focused *Make* magazine were both informative and taught aspiring garage biologists how to do everything from making microscopes out of $10 webcams and using their armpits as incubators for their cultured microbes to building their own contraption for running a gel electrophoresis.[385]

Some individuals took things a step further and both created their own open-source version of laboratory equipment for their person use and shared the file and plan with others. A famous example of this is Cathal Garvey's Dremelfuge – a 3-D printable rotor that attaches to a Dremel rotary tool that works as a centrifuge.[386] According to Cathal, it achieved the same results as a commercial centrifuge, but at a significantly reduced price – on the site, he cites that a new centrifuge costs $500, while a Dremel plus rotary part would cost around $100.[387]

While products like the Dremelfuge show the innovative potential and adaptability of DIYBio activities, they are not foolproof. Both in his article on magazine and during my interview with him, Patrik delivered a warning to potential Dremelfuge users. While it is an incredible concept and offers an essential lab tool for a fraction of the

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385 See Ledford, "Life Hackers" and D'haeseleer, "How to Set Up Your Own DIY Bio Lab".
386 Cathal Garvey, "DremelFuge – A One-Piece Centrifuge for Rotary Tools," *Thingiverse*, December 23, 2009. https://www.thingiverse.com/thing:1483. Accessed March 26, 2021.
387 Ibid.

market price, the 3-d printed rotor piece often shatters at higher speeds on the Dremel rotary tool.[388]

There have also been other individuals who have tried to create lab equipment that specifically targets biohackers and amateur science enthusiasts. Products like OpenPCR promise a low-cost yet accurate thermocycler to future purchasers at a fraction of the cost of new or even used ones from big companies like Thermo-Fisher.[389]

While these may be attractive at first glance from a market accessibility standpoint, there are two issues that limit its marketability and usefulness. First, the OpenPCR machine arrives to the purchaser completely unassembled – this means that the purchaser must assemble the machine, and users have reported that contaminants may have gotten into their machine during assembly.[390] Second, the $499 price tag, while cheaper than new PCR machines, is not necessarily cheaper than the second-hand lab equipment that community labs buy from online auction sites like eBay. Andy from BUGSS recounts a conversation he had with Lisa about a similar product from a manufacturer marketed towards biohackers:

> “We have a loaner of an 8 well thermocycler, and there are 16 out there that are run by Bluetooth, so you can run them from your phone, and cool whizzbang. The whole thing for about $1000, and Lisa said, when I told her, that she could get them for about $300 off eBay. So, you know, real ones. Big ones. And she said

[388] D’haeseleer, “How to Set Up Your Own DIY Bio Lab,” and Lim, “Interview with Patrik”.
[389] “OpenPCR,” *OpenPCR*, https://openpcr.org/. Accessed March 26, 2021.
[390] “Open Source PCR Thermocycler,” *Y Combinator*, August, 2020, https://news.ycombinator.com/item?id=24033878. Accessed March 26, 2021.

> for the cost of that, she could get 3 full-sized ones off eBay where, at least, one of them should be working at any given time."[391]

Therefore, while these products may be marketed towards biohackers, they often do not fit the budget or needs of community labs.

Of interest from the last quote from Andy as well is how community labs purchase equipment second-hand from online auction platforms. The comment that Lisa makes about how one of the three PCR machines purchase second-hand should work indicates another barrier to community lab capabilities in the market accessibility context. Purchasing from a second-hand market may get labs cheaper goods, but also increases the risk of defects and non-functional equipment, resulting in the loss of scarce financial resources.[392]

A less discussed pathway outside of purchasing available equipment and reagents is to obtain it through donations. The most straightforward way found in this research was direction donations from large biotech companies to a community lab for items like reagents. Community labs often have arrangements with reagent companies like Carolina Biological Supply or New England Biolabs to provide reagents for cheap or as donations.[393]

However, other donation mechanisms exist, and these involve local and professional connections. Community lab leaders sometimes get information from colleagues and others in their professional community about lab closures at universities

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[391] Lim, "Interview with Andy".
[392] For examples, see Lim, "Field Notes 076 – Coffee with Danny," February 08, 2020; Lim, "Interview with TJ,"; Lim, "Interview with Jay,"; Lim, "Interview with Bill,"; and Lim, "Interview with Angela".
[393] Ibid.

or other professional places. In such instances, community lab members may go to get some equipment, glassware, and other essentials they may need to help with their community lab operations.[394]

Information Accessibility

In the case of DIYBio, community labs leverage both the physical and virtual space that they occupy as a means of distributing scientific knowledge and skills. Trained amateurs or traditionally trained life scientists end up developing programs, hands-on experiences, and lectures to further disseminate their knowledge and expertise to a curious or interested audience.[395]

While these educative, explorative, and empowering activities were predominantly done physically, the COVID-19 pandemic has caused a dramatic change in how community labs operate. When COVID first emerged as a pandemic, community labs took the initiative and shut down their physical spaces to limit the potential spread of COVID in their local communities. During this time, they have innovated to continue their activities of education, empowerment, and exploration through online courses, panel

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[394] Ibid.

[395] See Field Notes 003. April 06, 2019. iGEM Orientation (First Meeting); Field Notes 008. April 13, 2019. Analyzing the Inner Harbor (Third Meeting); Field Notes 015. May 04, 2019. iGEM Meeting (5th Meeting); Field Notes 016. May 11, 2019. Analyzing the Inner Harbor (Sample + PCR) by BUGSS; Field Notes 017. May 11, 2019. iGEM Meeting (6th Meeting by BUGSS); Field Notes 019. May 16, 2019. Lab Skills Night (Gel Electrophoresis);Field Notes 026. June 01, 2019. Biotechnology Crash Course (Session 1) at Genspace; Field Notes 027. June 06, 2019. Biodiversity of Inner Harbor Biodisks Event at National Aquarium; Field Notes 029. June 08, 2019. iGEM Lab Session. Maintaining Sterile Samples; Field Notes 035. June 29, 2019. Inner Harbor Project (2016 Samples PCR); Field Notes 038. July 13, 2019. Inner Harbor Project – Large Gel Electrophoresis; Field Notes 039. July 20, 2019. Inner Harbor Project – Abbreviated Gel-Making; Field Notes 058. September 14, 2019. Wolbachia Class Seminar; Field Notes 081. March 02, 2020. Synthetic Biology Journal Club; an Interview with a BosLab Member. April 08, 2020.

discussions with scientists on salient topics of vaccine production and COVID-19 research, and hands-on experiments that people could do at home with household supplies.[396]

One thing that community labs are cognizant of when it comes to teaching courses and providing lectures is the diversity of their audience. Events can have people ranging anywhere from PhDs and PhD students in the life sciences to kids that are taking basic science courses at the elementary or middle school levels. With this consideration in mind, community lab instructors deliberately take a lowest common denominator approach: information is communicated so that the person with the least education in the group can understand the material.[397]

This does not mean that the highly educated are ignored. Rather, the instructors walk a tightrope between educating the amateurs while keeping the advanced students engaged. This often takes the form of conversations between the instructor and the advanced students to areas of interest the students have.[398]

Whether it is through courses, public projects, private projects, or collaboration projects across labs, people in community labs often try to share as much information as possible. This often takes the form of files, such as research papers or presentations, that people are willing to share. Some of these are shared physically – hands-on labs and lectures typically have information that the instructor prints out (or slides for a lecture) that are then distributed to the students.[399]

[396] Ibid.
[397] Ibid.
[398] Ibid.
[399] Ibid.

For digital files, people typically share them in three ways. The first is through direct transfer of files via e-mail. In this situation, someone typically makes a direct request inside a community lab to another member of the same community lab, which results in the transfer. The second is using communication applications like Slack for internal community lab documentation – while this could include information specific to the community lab like rules and procedures, protocols, and schedules, it can also include research articles, project data, and project records of interest for those involved in specific projects. Finally, community labs often leverage cloud resources like Google Drive and Microsoft Cloud to generate folders filled with content for specific group and personal projects. In this last case, individuals typically need to receive access from the administrator of the folder before they can look at the folder's contents.[400]

As a subset of files that people are interested in sharing, research papers can be both easy and difficult to access. Online resources such as Google Scholar and other search protocols certainly ease the process for finding articles of interest. However, many of these articles are typically behind paywalls: institutional financial barriers that require individuals without agreements to the journals (or institutions with agreements with said journals) to pay for the privilege to access a journal article.[401]

In the DIYBio context, many participants in community labs are professionals with formal ties to academia, industry, or government. This being the case, many of these individuals typically have access to reach behind these paywalls and obtain access to an

[400] Ibid.
[401] Ibid.

article that a member may be interested in. Thus, DIYBio community labs further a system of democratization by providing what was historically inaccessible to average citizens.[402]

The DIYBio community lab scene is unique in its intersectionality of both professional and amateur participants in the life sciences. Due to this interesting blend of amateurs and professionals, people can typically find or provide some resource that may help someone with a specific question they might have on some obscure life sciences topic. For those interested in mushrooms, for example, there is an active community online known as the Shroomery that people in community labs have pointed to. This forum, while the focus is on magic mushrooms, also goes into other areas such as mushroom safety, mushroom cultivation techniques, and other mycological areas of interest.[403]

The DIYBio community labs leverage information and communications technologies (ICTs) to work with each other across different geographics and time zones. The idea here is that having wider participation can only strengthen a project because it increases the manpower and the in-house expertise for a project. Many community labs use platforms like Zoom or Skype to hold open community and project meetings where people from around the globe can join in, provide their input, and potentially contribute to an ongoing project. Some major ones that leverage this platform to expand

[402] Ibid.
[403] Ibid.

involvement include the Open Insulin Project, as well as smaller efforts like the BioCurious bioprinter and Cuttlefish Wranglin' projects.[404]

While there are ways that information distribution and remote collaboration methods have contributed to the democratization of the life sciences, there are very real limits to this phenomenon. This is because focusing on these elements alone fail to account for phenomena in the DIYBio community lab that continue to create very real barriers to the democratization of the life sciences.

While not mentioned explicitly by community members, there are also implications with the way that community labs distribute information. The most obvious implications concern how community labs share and store research papers. While this has been an option for community labs and biohackers, there are existing examples where such efforts have resulted in court injunctions and legal disputes.[405] If the DIYBio community is not careful, this may also be an avenue that large journal publishers like Elsevier could pursue, which would have a negative impact on the community's ability to access and distribute journal article information.[406]

Another implication of how community lab members try to spread knowledge works in conjunction with the fact that participation in this space is largely voluntary. Therefore, many open-source platforms and forums for the DIYBio community tend to

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[404] Ibid.
[405] Fiona MacDonald. *ScienceAlert.com*. "Researcher Illegally Shares Millions of Science Papers Free Online to Spread Knowledge". Accessed December 15, 2020. https://www.sciencealert.com/this-woman-has-illegally-uploaded-millions-of-journal-articles-in-an-attempt-to-open-up-science
[406] Ibid.

be poorly structured and poorly curated.[407] Popular platforms like DIYBio.org provide basic information in its tabs but digging in deeper to find specific topics of interest can be exceedingly difficult since the structure of these websites are built with little planning. Therefore, while this means that the information that people are seeking may be on the site, they may not be able to find it.[408]

In addition, these sites are also updated inconsistently, resulting in potentially inaccurate information. For example, community labs like Open Bio Labs and Biotech without Borders are still listed as open and operation on the DIYbio.org site even though both of those labs are currently shut down.[409]

This somewhat loose and decentralized approach to maintaining websites also extends to how people interact across community labs. Outside of projects that are prominently advertised in mainstream media or on community lab websites, members interested in finding other people in community labs interested in specific topics typically need to do a fair amount of networking and research. This typically means that many community labs end up doing the same projects without realizing that there is repetition across community labs.[410]

Further, once someone finds other people doing the thing they are interested in a different lab, there are other obstacles to overcome. ICT has come a significant way to letting people hold meetings and share information across temporal and geographic

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[407] Lalitha Sundaram, "Biosafety in DIY-Bio Laboratories: From Hype to Policy," *EMBO Reports* e52506 (2021): 1 – 5.
[408] Ibid.
[409] *DIYBio.org*. "DIYBio Local". Accessed December 15, 2020. https://diybio.org/local/
[410] Ibid.

divides. However, even time zone differences of three hours can be sufficiently burdensome for people to not participate in U.S.-based cross-country projects. For project meetings on the East Coast that happen in the evening, the time in the West Coast tends to interfere with individuals that have 9-5 jobs. The same is true vice versa, where projects that start at 7:00 PM on the West Coast mean a late start time of 10:00 PM for people on the East Coast. While people can use technology to overcome geographic differences, these temporal differences can end up being a major barrier towards cross-country engagement.[411]

2020 has also taught the global community that virtual conference platforms like Zoom and Skype are plagued with technical issues. Poor connectivity, issues with volume settings, too many live mics, and other obstacles continue to hinder collaboration across virtual platforms.[412]

If a person does manage to join a community project in a geographically distal community lab, there could still be the problem of gaining access to a common Google Drive or Microsoft Cloud shared drive. Typically, one person has administrator privileges for a project folder as a type of gatekeeper mechanism. However, there are situations where these gatekeepers may not be known outside of the project, so it takes time to figure out who to request permissions from. This problem gets worse in situations where the gatekeeper ends up on holiday, travel, or leaving the community lab altogether. While the best-case scenario here is that the gatekeeper is contacted sufficiently enough to allow

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[411] Ibid.
[412] Ibid.

access, the worst-case scenario is one where a project could die out because no one associated with a project is both present at the lab and can provide access to the data in the folder – the data in the folder can essentially be lost forever.[413]

Even if the project is revived after a hiatus, it is likely that the participants, both old and new, would have to essentially start from the beginning. This is clear from the STS literature, which highlights how tacit knowledge is not only difficult to cultivate and use, but it also deteriorates with from a lack of use. Further, the fragmented and distal nature of work processes would likely have significant negative impacts on developing cohesion and a culture of trust and collaboration. This, in turn, would likely significantly impede progress on the project as conditions to develop, transfer, and use tacit knowledge would be significantly diminished in this type of working environment.[414]

Biorisk Threat Evaluation of U.S. Community Labs through Degree of Democratization Data

DIYBio Community Labs Represent Limited Democratization - Market Accessibility

DIYBio community labs represent a certain amount of life sciences democratization in several ways. First, community labs explicitly have access to resources and instructions on how to repurpose household goods to engage in the life sciences. Second, independent members of the DIYBio community have generated open-source products to increase accessibility of tools like centrifuges to others that might be

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[413] Ibid.
[414] See Hoyt, *Long Shot*, Loc 71 – 87; Ben Ouagrham-Gormley, *Barriers to Bioweapons* (2014), 17 – 24; and Vogel, *Phantom Menace or Looming Danger*, Loc 1925.

interested in exploring the life sciences outside of academia, industry, and government. Third, new companies have flooded the market with cheaper tools that are specifically marketed towards the DIYBio community. Fourth, second-hand markets like eBay on both online and physical venues is the typical practice at community labs now due to convenience and cost.

That said, there are significant barriers that have yet to be overcome for DIYBio community labs to be fully democratized rendition of the life sciences. While there are instructions on how to repurpose existing equipment to build a makeshift DIYBiology lab, per the last chapter's findings, having access to equipment does not automatically confer tacit knowledge or expertise in the life sciences – that requires hours of study, repeated efforts, and preferably a mentor to guide a novice through the process of learning everything from basic biology to more specialized areas of interest. In addition, while open-source and member-developed tools are intriguing and could offer increased accessibility to biohackers, the inability to consistently test the products for quality control issues may limit the attraction to these types of tools. Further, while new companies are marketing equipment to DIYBio community labs, these spaces are not purchasing these products due to the presence of cheaper alternatives that are far more effective for and convenient to the end user. Finally, even the cheap price of second-hand equipment purchases through auction platforms like eBay are not necessarily as cost-effective or cheap as members may think due to potentially damaged or unusable goods.

Therefore, the degree of democratization data indicates that DIYBio represents a limited form of life sciences democratization based on the market accessibility information. While prices have gotten cheaper and more alternatives for DIYBio members are available, there are still significant tacit knowledge, financial, and operational barriers to entry that limit the community, as well as limit the opportunity for a broader population of people to join the community.

DIYBio Community Labs Represent Limited Democratization – Information Accessibility

U.S. DIYBio community labs have significantly leveraged the physical and virtual spaces that they occupy to distribute scientific knowledge and skills through everything from hands-on classes to virtual seminars. This community has been particularly adroit at leveraging the internet as a means of fostering community and communication following the emergence of the ongoing the COVID-19 pandemic.

Whether it is through courses, public projects, private projects, or collaboration projects across labs, people in community labs often try to share as much information as possible through both physical and virtual means as a form of democratizing life sciences knowledge. In addition, DIYBio community labs leverage information and communications technologies (ICTs) to execute projects that, theoretically, are no longer bound by geographic considerations.

That said, there are still significant barriers that exist when it comes to information accessibility in the DIYBio context. Community lab and biohacker actions like creating databases of articles acquired from behind paywalls leaves the group vulnerable to legal actions. Further, DIYBio websites and forums are typically poorly curated and updated as no one person has a direct responsibility to do such tasks – this is where the volunteer nature of DIYBio suffers significant shortfalls. Further, while the DIYBio community is perceived as monolithic, it is a highly decentralized set of groups and individuals with shared passions and interests, which has significant negative effects on the ability for community members to find the right people to talk with concerning a shared interest or project. If people in geographically distant locations can find each other and set up a project, even bicoastal video calls in the U.S. can generate significant timing issues. Finally, non-geographically bound projects within a volunteer-based community can make it difficult for people to share information, and even generate the cohesion and communal spirit necessary to develop, transfer, and use tacit knowledge, which can pose significant barriers to project progress.

Therefore, the degree of democratization data indicates that DIYBio represents a limited form life sciences democratization based on information accessibility. While community labs have made great strides in leveraging the internet to share knowledge and democratize technology, there are significant socio-organizational, temporal, and legal barriers that continue to limit who can participate in the life sciences.

Conclusion

While the emergence of DIYBio community labs represents a certain amount of life sciences democratization, it does not mean that anyone anywhere now has access to all the equipment and information in the world. Further, having access solely to information and equipment ignores tacit knowledge barriers that, as discussed in the previous chapter, make doing complex scientific tasks and projects difficult. Therefore, insights from the intersection of the ICT and STS literatures have shed light on how far DIYBio community labs must go before they can be seen as a rendition of completely democratized biology. This chapter concludes with some brief implications and limitations on the biorisk threat assessment using U.S. community lab drive data.

Implications

In the case of U.S. DIYBio community lab drives, the biorisk threats associated with these spaces are a mixed bag. In terms of factors that make it so that complex scientific tasks are more likely to be achieved, U.S. community labs have cultivated the right kind of culture to ease the development, use, and transfer of tacit knowledge and expertise. These spaces are casual, friendly, and experts are more than happy to teach others what they know. Furthermore, individuals are willingly to come together organically to accomplish projects, and even work together across different stages of the scientific protocol to help make the process more efficient and help troubleshoot problems. Further, the design data does indicate that community labs may have leadership that can help cultivate this type of ideal space for completing complex scientific tasks.

However, the data also indicates that there are also elements of community labs that could create significant issues and delays in successfully completing a scientific project. Leadership in community lab spaces are forced to carry significant amounts of duties and responsibilities that serve as an obstacle for leadership to be fully aware of what is going on with a project. Furthermore, the lack of stable participants at times can generate significant delays in research progress – this is particularly true if the individual is one whose expertise is very much needed or appreciated for the success of the project. Furthermore, community labs suffer from significant limitations in their budgets, which results in situations where projects may not have access to the necessary equipment and reagents to make progress.

Therefore, at this current moment in time, it appears that U.S. DIYBio community labs may have some of the characteristics that enable the completion of a complex scientific project, but may lack others. That said, it is reasonable to assume that community labs are slowly improving on their ability to conduct good science given the emergent success of the Barcoding the Inner Harbor project, which is culminating in a scientific report and associated with academic institutions.

Limitations

This analysis has three main limitations. There are questions about being able to generalize the findings from this data to other groups within the DIYBio community. It is also likely difficult to generalize this data to community labs in other regions due to how different regions operate with different laws and likely have different interests in activities. Therefore, this analysis is only truly applicable to DIYBiology community labs based in the U.S. Furthermore, the case study used to highlight the design data related to U.S. DIYBio labs was BUGSS: the community lab that I spent the most amount of time at. Therefore, the ability to generalize the experiences at BUGSS to other community lab experiences is limited.

Second, it is important to note that the STS literature that I used refers to complex scientific projects and tasks that are not perfectly analogous to those within the DIYBio context. For example, Ben Ouagrham-Gormley's studies of socio-organizational components affecting the development of complex biological weapons systems and Hoyt's studies on the development of vaccines are significantly more complex than the project I used as a case study – one where people retrieved, prepared, processed, and analyzed samples.

Third, the design data I gathered for this dissertation research was entirely qualitative and acquired through personal on-site visits for observational data, and virtual interviews for interview data. My ability to gather this data was enabled largely through my prior interactions and relationship-building with the community 3 years prior to the start of my dissertation research. The large dependence on personal experiences and memories, particularly for the interview data, does introduce the issue of self-reported data bias.

CHAPTER SEVEN – CONCLUSIONS AND RECOMMENDATIONS

Biorisk vs. DIYBio Narrative, Revisited

Introduction

This dissertation was prompted by the perpetuation of narratives concerning the DIYBio community. On the one hand, advances in technology and ease of access to materials, equipment, reagents, and information were driving concerns that the democratization of the life science could significantly raise the risks of a harmful biological events in the world. On the other hand, the DIYBio community's narrative is one where the democratization of the life sciences is for the good of all by enabling people to understand science, explore their surroundings, apply science to their personal lives and ambitions, and to enable a broader audience to participate in everything from discussions on science and technology to potentially generating new biotech products with outcomes that can help humanity.

The subsequent data and analysis from this research indicate that neither narrative is completely wrong. Changes over time like advancing capabilities and increased access *do* matter. The DIYBio community would not have been possible without increased market and community accessibility factors. These factors, in turn, helped founders with adequate resources create these spaces, and allowed laypeople with an interest in science to have access to life sciences education and a platform to do life sciences projects and experiments without being a part of, or needing to enroll in, traditional academic, industrial, and government institutions.

Following along with the theme of change, I begin this chapter with an abbreviated exposition on how COVID impacted the activities and operations of the DIYBio community. I then provide a summary of the findings of this study. Finally, I conclude this dissertation by providing and expanding on 3 recommendations informed by the research. These recommendations include the need for the biorisk community to expand its current threat assessment to include motivational, organizational, and socio-technical considerations from the bioterrorism and STS literatures, the necessity of building bridges and breaking silos between the biorisk and DIYBiology community, and the need to incorporate current and past DIYBio community members to integrate the latest changes and trends of the group in future threat assessments.

DIYBio in a Time of COVID

It only took 2 months for COVID-19 to go from WHO-announced mysterious pneumonia-causing disease in Wuhan to its declaration as a National Emergency in the United States by then-President Donald Trump.[415] From March 8 – July 15, 2020, counties that, in the aggregate, accounted for 80% of the U.S. population were identified as COVID-19 hotspots.[416]

As the U.S. health infrastructure was overwhelmed by rapidly spiking cases of COVID, state and local governments began to impose social distancing measures to slow

[415] AJMC Staff. "A Timeline of COVID-19 Developments in 2020," *The American Journal of Managed Care*, January 1, 2021, https://www.ajmc.com/view/a-timeline-of-covid19-developments-in-2020. Accessed March 23, 2021.
[416] Oster et al., "Trends in Number and Distribution of COVID-19 Hotspot Counties – United States, March 8 – July 15, 2020," *CDC*, August 21, 2020, https://www.cdc.gov/mmwr/volumes/69/wr/mm6933e2.htm. Accessed March 23, 2021.

the spread of the disease, including banning large social gatherings, closing schools, closing entertainment venues, and imposing shelter-in-place directives.[417] As social gathering spaces, community labs were required to close their doors to help slow the spread of COVID as well.

In a webinar hosted by MIT Media Lab on June 17th, 2020, I moderated a panel of community lab leaders and founders and infection preventionist expert Dr. Saskia Popescu on the challenges that community labs have faced during the pandemic[418]. For community labs, closing their physical labs exacerbated immense financial difficulties, particularly for spaces like BioCurious which depends significantly on its entrepreneur members.[419]

However, as mentioned in Chapter 6, they were able to find ways to pivot their operations online. Many held meetings, seminars, and even some hands-on lab technique courses with house-hold ingredients to continue engaging with their communities, and even hosting COVID-related events to empower fellow citizens like 1) convening expert panels to discuss the promise and challenges of vaccine development and clinical trials; 2) making DIY disinfectants; 3) discussing health inequities related to insulin access; and

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[417] Charles Courtemanche, Joseph Garuccio, Anh Le, Joshua Pinkston, and Aaron Yelowitz, "Strong Social Distancing Measures in the United States Reduced the COVID-19 Growth Rate," *Health Affairs* 39, no. 7 (2020): 1237 – 1246.

[418] Yong-Bee Lim, "Commentary – Reopening Community Labs in a Time of COVID: Balancing the Needs and Risks of DIYBio Spaces During a Global Pandemic," *Pandora Report*, July 3, 2020, https://pandorareport.org/2020/07/03/commentary-reopening-community-labs-in-a-time-of-covid-balancing-the-needs-and-risks-of-diybio-spaces-during-a-global-pandemic/. Accessed March 24, 2021.

[419] During my interview with Maria from BioCurious, she had indicated that these entrepreneur members paid significant amounts of money - $1000 to $1200 per month for a dedicated office. All but one of the offices had been rented out during this interview period – April 2020. For more, see Lim, "Interview with Maria," April 03, 2020.

4) being a resource for the public to ask questions about science through weekly virtual calls to catch up on the latest COVID news.[420]

For some, the emergence of COVID and the online pivot was ironically helpful. Biotech without Borders lost its physical lab space following the death of the building owner in February 2020. With no physical space, they had wondered what they might do to reopen the lab but realized that COVID allowed them the opportunity to operate entirely online with no physical lab space and, thus, no rent.[421]

The emergence of COVID was also a clarion call to arms against the pandemic. DIYBio members from around the world came together online to find solutions to the various problems that COVID-19 was presenting to the world. At an Australian community lab for citizen scientists called Biofoundry, members allegedly created a COVID-19 test kit in March that was simpler, cheaper, and faster than any existing test during that time.[422]

The rise of COVID also marked the advent of a global online collaboration platform for biotechnology, DIYbio, and open science hardware projects called Just One Giant Lab (JOGL). This platform, founded by former president of the French DIYBio community lab space called La Paillasse, grew to over a thousand participants collaborating virtually on over 500 projects. Most of these projects are related to finding solutions to problems like testing shortages, personal protective equipment (PPE), and

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[420] Lim, "Commentary – Reopening Community Labs,"
[421] Lim, "Interview with Danny".
[422] Andrew Lapworth, "From Coronavirus Tests to Open-Source Insulin and Beyond: 'Biohackers' are Showing the Power of DIY Science," *The Conversation*, May 10, 2020, https://theconversation.com/from-coronavirus-tests-to-open-source-insulin-and-beyond-biohackers-are-showing-the-power-of-diy-science-138019. Accessed March 26, 2021.

syringe pump system shortages. JOGL even caught the attention of AXA, resulting in small funding opportunities for particularly promising projects.[423]

While some DIYBio community members were looking to engage in global collaborations through JOGL on tests and PPE, others were looking to collaborate on developing a DIY vaccine. One such vaccine was pursued by perennial DIYBio polarizer Dr. Josiah Zayner with two other biohackers – Daria Dantseva and David Ishee. He and his team sought to replicate a DNA-based COVID-19 vaccine that appeared to work in monkeys and livestream their inoculation and subsequent weekly reports through live broadcasts on social media platforms.[424]

The other major nominally-DIY vaccine effort was done through a group which called itself the Rapid Deployment Vaccine Collaborative (RaDVaC). Portraying itself as a group of citizen scientists, this group includes academic elites with backgrounds as researchers, technologists, and science enthusiasts associated with institutions like Harvard University and MIT.[425] As of late October 2020, over 50 people have taken intranasally-administered doses of the vaccine, including geneticist Dr. George Church.

The case of RaDVaC is quite unique in how the academic elite appropriated the language of the DIYBio community. RaDVaC identifies itself as a "free and open-source

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[423] Cherise Fong, "Just One Giant Hackathon Against COVID-19," *Makery France*, May 5, 2020, https://www.makery.info/en/2020/05/05/english-just-one-giant-hackathon-against-covid-19/. Accessed March 26, 2021.
[424] Kristen V. Brown, "Home-Made COVID Vaccine Appeared to Work, but Questions Remained," *Bloomberg*, October 10, 2020, https://www.bloomberg.com/news/articles/2020-10-10/home-made-covid-vaccine-appeared-to-work-but-questions-remained. Accessed March 26, 2021.
[425] Antonio Regalado, "Some Scientists are Taking a DIY Coronavirus Vaccine, and Nobody Knows if it's Legal or if it Works," *MIT Technology Review*, July 29, 2020, https://www.technologyreview.com/2020/07/29/1005720/george-church-diy-coronavirus-vaccine/. Accessed March 26, 2021.

vaccine R&D project" run by a group of citizen scientists who are seeking to disrupt the status quo to do their part in the fight against COVID.[426] While this could be seen as part of the community lab ideology discussed in Chapter 4 with the drive data, RaDVaC deviates significantly from U.S. DIYBiology community labs in that they attempted to promote self-experimentation by reaching out to not only their personal networks, but directly to DIYBiology community labs as well. When Lisa from BUGSS received an e-mail from RaDVaC soliciting members to try the vaccine, she sent a response stating that BUGSS does not engage in or affiliate with projects involving self-experiment or the self-administration of biologically active substances.[427]

Findings

My research indicates that the current state of U.S. community biology labs does not contribute to a rise in biorisk threat. In terms of its past and current drives, the drive data indicates that community lab leaders and members may be ideologically disruptive, but the lack the propensity for violence necessary to be considered a heightened biorisk threat.

In terms of its design, community labs naturally cultivate an open, trusting environment that allows collaboration within and across groups working at different portions of the science protocol, and have leadership that helps maintain this collaborative environment and provide a certain amount of oversight and communication.

[426] "FAQ," *RaDVaC,* https://radvac.org/faq/. Accessed March 26, 2021.
[427] Personal E-mail Communication, July 31, 2020.

However, the number of responsibilities placed on leaders, the financial leanness of these spaces, the difficulties in getting working reagents and equipment, and the unstable attendance of members over time in these volunteer spaces create significant obstacles to developing, transferring, and using the tacit knowledge and expertise necessary to complete complex science experiments.

In terms of the degree to which U.S. DIYBiology community labs represent a complete democratization of the life sciences, the degree of democratization data suggests that these spaces still face significant obstacles that limit their ability to be more accessible. On the market accessibility angle, quality control issues with self-made tools, the financial and reliability issues associated with purchasing either second-hand equipment or equipment marketed directly to biohackers, and the fact that access to equipment does not automatically transfer tacit knowledge and expertise to an amateur are all noteworthy barriers at this time. Finally, on the information accessibility angle, temporal, technical, legal, and socio-organizational issues also present as significant obstacles to further democratization.

These findings run directly counter to both the underlying assumptions of the biorisk narrative, which presumes that U.S. community labs 1) have malicious intent; 2) can do complex scientific activities successfully anywhere and at any time; and 3) represent a fully democratized rendition of the life sciences where anyone can access information and equipment. Thus, the biorisk narrative concerning the DIYBio community should be updated and reconsidered accordingly. In addition, future assessments concerning emerging socio-technical phenomena like the DIYBio community should incorporate a broader set of factors to consider threat, including organizational, social, and technical details.

While elements of the biorisk and DIYBio communities do intermingle with each other on occasion, there also needs to be a greater drive to increase interactions between these two communities to break through each other's siloes and create a new, more accurate narrative – a narrative built by both communities rather than two narratives that can find no common ground. As this narrative develops and strengthens over time, this would also be a great opportunity to better coordinate messaging between the biorisk and DIYBio communities when it comes to interacting with the news media.

However, in some respects, the capabilities of citizen scientists and DIYBio members are changing over time. The Barcoding the Inner Harbor can be considered a success given that the team is putting together an ecological report with academic institutions like IMET and the National Aquarium. There are also projects, such as the Basic Respirator on JOGL, that have made significant strides in going from concept to evaluation and identifying potential manufacturers for components of this citizen science effort.[428] It will be necessary to update assessments of community labs and other parts of the DIYBio community as activities, motivations, and capabilities change.

[428] Hunter Futo, "Basic Respirator," *JOGL*, March 25, 2021, https://app.jogl.io/project/212. Accessed March 26, 2021.

Recommendation 1: Incorporating Motivational, Organizational, and Socio-Technical Components to Threat Assessments

My research highlights how current threat assessments suffer from significant gaps. By focusing solely on the technical capabilities and access to protocols and other forms of explicit knowledge, the biorisk community has arrived at a conclusion that is oversimplified.

Community labs are an intriguing phenomenon. On the one hand, the biorisk narrative is correct – a community such as the DIYBio movement would not exist without increased access to equipment and information. But this is only part of the equation with community labs. These spaces were started by people that not only desired to disrupt the way science was traditionally conducted – they were also started by people that wanted to create a community place where those interested in science could feel welcome and even try their hand at simple projects.

The biorisk community could avoid such myopic threat assessments in the future through two means. First, incorporating motivation from the bioterrorism literature into the assessment is important. In his edited volume *Toxic Terror*, Tucker highlighted how incorporating motivation into a threat assessment, in addition to a capabilities-based approach helps in obtaining a more accurate, holistic measure of whether a group may seek to research, acquire, and use biological weapons. Therefore, if a group has the capabilities, but not the motivation, to acquire and use a biological weapon, the biorisk community may be less concerned about the possibility of a bioterrorism attack.[429]

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[429] Jonathan B. Tucker, "Introduction," In *Toxic Terror*, 2000: 6 – 12.

In addition to incorporating motivation, the biorisk community should also consider adding factors that the STS literature has found salient when it comes to producing biological weapons and successfully accomplishing complex scientific projects. As Vogel's "Reframing Biosecurity" points out, the dominant framework for assessing threats is through what she terms the biotech revolution model – a model that relies mostly on looking at access to technical capabilities and information. By expanding the assessment to acknowledge and include the importance of organizational and socio-technical factors in learning, producing, using, and transferring tacit knowledge to accomplish complex scientific tasks, the biorisk community can simultaneously minimize the risk of inaccurate threat assessments while also gaining a more nuanced understanding of the phenomenon they are assessing.[430]

Recommendation 2: Breaking Silos and Building Bridges Between the Biorisk and DIYBio Communities

The biorisk and DIYBio communities have, to date, been oppositional in terms of their rhetoric. However, elements of both communities have interacted in a positive manner since 2009. The FBI and stakeholders in the DIYBio community have interacted with each other over the years to discuss everything from biosafety and biosecurity to the future of biotech.[431]

[430] Vogel, "Framing Insecurity".
[431] Tocchetti and Aguiton, "Is an FBI Agent".

Rather than turn sour over the years, this relationship has ended up being mutually beneficially to both parties. For the FBI, they were able to get early buy-in from the community to engage in safe practices, report suspected unsafe behavior, and gain access to a space that not many in the biorisk community had been to at that time. For the DIYBio community, having a relationship with the FBI gained the community a perception of legitimacy, a potential mechanism to scare away individuals that may not have had the best of intentions in community lab spaces, and an advocate for situations where the news media and the biorisk community put a negative spotlight on the community.[432]

While the main catalyst for the bridging effort no longer works regularly with the DIYBio community, the Weapons of Mass Destruction Directorate at the FBI continues to maintain contact with the community. Therefore, one way to begin building bridges is for the FBI and the DIYBio community to hold a conference or a meeting (the last one having been in 2012) so each side can update the other on any changes, renew relationships, and see if that action precipitates future meetings with a different set of biorisk stakeholders.

A second avenue that the DIYBio community could take is a more international angle. The DIYBio community has long been discussed at the Biological Weapons Convention's Meeting of States Parties and the Meeting of the Experts. However, Dana Perkins notes that the increase in amateur engagement in the life sciences makes a strong

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[432] Ibid.

case that this community should be invited to create and strengthen a culture of responsibility in the context of biosafety.

A third avenue would be leveraging the growing network of connectors that exist at the nexus of biorisk and DIYBio. As DIYBio has grown, evolved, and hosted larger global events, the number of biorisk individuals that attend these events have also grown, including people like myself, Gigi Gronvall, Sam Weiss Evans, Piers Millett, David Gillum, and Lalitha Sundaram. Using these people as interlocutors and potential organizers for meetings and conferences would also be a way forward in breaking down silos and building bridges between the two communities.

Recommendation 3: Incorporating Past and Present DIYBio Members to Inform Future Threat Assessments

As mentioned previously in this concluding chapter, the state of DIYBio may be changing. In the past, it was unheard of for DIYBio projects to not only succeed, but end up collaborating on and producing an academic piece with scientists in academia. Genspace was the community lab incubator that housed Opentrons – an open-source lab automation tool that users can program to automate their pipetting.

As platforms shift and activities change, the biorisk community should consider adding DIYBio members to future threat assessment panels that look at the community for two reasons. First, these members are subject matter experts of their community, and their feedback could be reliable. Second, particularly if the biorisk community could include a DIYBio leader into the threat assessment, they are likely to get the most accurate data relating to activities in the community – this is because community lab leaders typically communicate with each other on a regular basis. Finally,

Conclusions

This dissertation has shown that a capabilities-based threat assessment is insufficient when it comes to a phenomenon like DIYBio. Further, this dissertation highlights not only the current capabilities of the U.S. DIYBio community, but also its limitations.

However, 2020 has shown us that things may be slowly changing in the DIYBio community. While global cooperation was something that occurred in the past, the emergence of the JOGL platform as a dedicated global hub for people to connect and work together potentially represents a significant change in how DIYBio members interact, collaborate, and succeed or fail in completing complex scientific tasks. Therefore, a full assessment of past, current, and ongoing projects, as well as trends in which ones appear to succeed and fail, would be a remarkably interesting case study to include in the DIYBio literature.

In addition to a study on the JOGL platform, future DIYBio literature work can focus on an ethnographic approach to other communities within the DIYBio umbrella. This past Global BioSummit saw a growing chasm emerge between the community lab group and a group commonly referred to as grinders – biohackers who engage in body modification through implanting, changing out, and some engaging in surgical procedures to either improve their existing biology or bring about a desired change. The chasm emerging between these two groups could signal fragmentation of the movement, which would have implications that should be studied.

Finally, in the spirit of democratizing access to technology and materials, there are international efforts underway through initiatives like the Free Genes Project, as well as groups like the Open Bioeconomy Lab, to allow more regions access to foundational and enabling technologies – their goal is particularly focused on increasing this access to Global South countries. Future studies in this area could focus on the goals, methods, how effective they are in achieving their goals, and the outcomes and implications of these efforts.

APPENDIX A: CODEBOOK FROM NVIVO

Name	Description
Community Lab Management	This node covers how community labs are managed. Subnodes here include the types of activities community labs engage in, their financials (funding in and funding out), an overview of their capabilities, and how they are organized.
Activity Categories	This subnode collates data related to the types of activities that community labs were found to engage in throughout this dissertation research. The four subcategories of activities that this research found included: 1) Education 2) Exploration 3) Empowerment 4) Entrepreneurship
Education	This subnode collates data related to community lab activities that are educational in nature. These can be structured (such as in classes), but can also be impromptu and unstructured (conversations that arise ad hoc about scientific topics of interest).
Empowerment	This subnode collates data on community lab activities that enable individuals and group members to empower themselves and others to address issues ranging from the personal to the societal.
Entrepreneurship	This subnode collates data of community lab activities that support and enable individuals to pursue entrepreneurial ventures.
Exploration	This subnode collates data on community lab activities that allow individuals and groups to explore themselves, new subject areas, and their environment.
Capabilities	This subnode collates data on the capabilities that exist in community labs visited during this dissertation. Many previous studies of community labs consider them to potentially

Name	Description
	be highly sophisticated due to cheapening costs of technologies, as well as a market surplus of reusable biotech goods. To address this gap, capabilities collates data on the type of equipment (hardware, software, and glassware), reagents, and protocols that community labs acquire and use.
Equipment	This subnode collates data on references to the equipment that community labs acquire and use.
Hardware	This subnode collates data on references to the hardware that community labs acquire and use.
Software	This subnode collates data on references to the software that community labs acquire and use.
Expertise	This code refers to any references of expertise that community lab members reference in regards to their own (or to other community members') expertise.
Explicit Knowledge	This code collates for data that references instances where community labs discuss explicit knowledge acquisition.
Materials	This codes collates data that references the biological substrates and materials the community lab uses.
Protocols	This subnode collates data on references to the protocols that community labs acquire and use.
Reagents	This subnode collates data on references to the reagents that community labs acquire and use.
Financials	This subnode collates data related to the financial operation of community labs. Community labs, like most organizations, have factors that bring in funding, and then factors that expend received funds. This dissertation research divided these factors out into subcategories of "Funding In" and "Funding Expenditures"

Name	Description
Funding Expenditure	This subnode collates data of community lab financial expenditures. This dissertation research found the following categories of how funding was used: 1) Insurance 2) Permits 3) Rent 4) Reagents 5) Equipment 6) Food/Refreshments
Equipment	This subnode collates data on references to equipment as a community lab financial expenditure.
Food and Refreshments	This subnode collates data on references to food and refreshments as a community lab financial expenditure.
Insurance	This subnode collates data on references to insurance as a community lab financial expenditure.
Outreach	This code collates data that references outreach mechanisms (like website maintenance, fees for participating in public events, etc.) that community labs incur during their operations.
Paid Staff	This code collates all references to paid staff or paid individuals in the community lab context.
Permits and Inspections	This subnode collates data on references to permits and inspections as a community lab financial expenditure.
Reagents	This subnode collates data on references to reagents as a community lab financial expenditure.
Rent	This subnode collates data on references to rent as a community lab financial expenditure.
Utilities	This code collates all data that reference utilities (such as water, electricity, heat, internet, and others) as a funding expenditure for community labs.
Funding In	This subnode collates data on how community labs bring in financial resources into their

Name	Description
	organization. The main ways this dissertation found community labs brought funds in were through: 1) Private Donations 2) Grants 3) Crowdsourcing 4) Classes 5) Membership Fees (Gym Membership Model) 6) Additional Donations
Additional Donations	This subnode collates data on additional donations as a mechanism for community labs to receive funding. These donations differ from private donations in that they are not necessarily logged as formal donations. This could be things like donating into a snack jar to help purchase refreshments and food, purchasing food for events and sharing with others, and other such contributions.
Classes	This subnode collates data on classes as a mechanism for community labs to receive funding.
Community Lab Membership Fees	This subnode collates data on community lab membership fees as a mechanism for community labs to receive funding.
Crowdsourcing	This subnode collates data on crowdsourcing as a mechanism for community labs to receive funding.
Entrepreneurially-Derived Revenue	This code collates all data that references building a project to pay for the running and upkeep of a community lab.
Equipment and Reagent Resale	This code collates data that references when equipment and reagents are sold (or re-sold) to gain funds for the community lab.
Grants	This subnode collates data on grants as a mechanism for community labs to receive funding.
Private Donations	This subnode collates data on private donations as a mechanism for community labs to receive funding.

Name	Description
Rental of Space	This code collates all data that references income for a community lab from renting out the space for other events or for other groups.
Geographic Considerations	This code collates references to how geography has an effect on community lab development and management.
Effects on Activities	This code collates references to how geography appears to affect the types of activities done in community lab.
Effects on Capabilities	This code collates data that references how geographic location may affect the capabilities of a community lab.
Effects on Organizational Style	This code collates data that references how geography and location affect community labs organization preferences and styles.
Effects on Participation Style	This code collates references to how geography affects the participation style of community labs.
Effects on Values	This code collates all references to how geography has effects on the values of community labs.
Organizational Style	This subnode collates data to how community labs are organized. Organizations typically fall under two typologies - vertical (hierarchical) organizations where there are clear delineations between decision-makers (leaders) and members, and horizontal (flat or egalitarian) organizations where there are few to no layers between decision-makers and members.
Horizontal (Flat) Organization	This subnode collates data on elements where community labs exhibit vertical (hierarchical) organization characteristics - few to no layers between decision-makers and members. This dissertation found 3 categories of data that corresponded to horizontal organizations. These included the participant structure, the

Name	Description
	roles that participants fulfilled, and how the organization assigned tasks.
Participant Roles	This subnode collates data on the roles that participants fill in organizations that display flat tendencies.
Participant Structure	This subnode collates data on mapping of members in the community lab context. This data is exactly like that of an organizational chart (and would have very few layers due to the egalitarian structure).
Tasks	This subnode collates information related to how participants interact to assign and complete tasks.
Vertical (Hierarchical)	This subnode collates data on elements where community labs exhibit vertical (hierarchical) organization characteristics - clear delineations between decision-makers (leaders) and members. This dissertation found 4 categories of data that corresponded to vertical organizations. These included the leadership structure, what leadership roles existed, what roles these leaders filled in the organization, how the organization chose leaders, and how the organization would assign tasks.
Choosing Leaders	This subnode collates data related to how leaders are chosen for their positions. This process can range from a highly formalized to an ad hoc process.
Leadership Role	This subnode collates data on the roles and tasks associated with different leadership tiers and different leadership roles.
Leadership Structure	This subnode collates data on the mapping of leadership to members in the community lab context. This data is exactly like that of an organizational chart.
Tasks	This subnode collates information related to how tasks leaders interact to assign and complete tasks.

Name	Description
Participation Style	This subnode compiles data on the participation style of community labs. This research found two major categories of participation. One is volunteer-driven, where participants from leadership to members are volunteers. The other is paid staff, where members of the community lab or leadership may be paid wages to perform certain tasks and help operate the community lab.
Paid Staff	This subnode collates data of evidence where community labs operate with paid staff. This is where members of the community lab or leadership may be paid wages to perform certain tasks and help operate the community lab.
Negative Implications	This subnode collates data on the negative implications of having paid staff to run tasks and operations in a community lab. This dissertation study found three main negative outcomes - High Financial Overhead, Increased Operational Complexity, and Dependence.
Dependence	This subnode collates data that references instances where community lab organizations with paid staff display evidence of dependence - a diminished autonomy compared to labs that operate that are volunteer-driven. This includes obligations to outside institutions, curbing activities or initiatives at the behest of a funding or oversight group, or other such evidence of autonomy diminishment.
High Financial Overhead	This subnode collates data on references to high financial overhead related due to paid staff operations at a community lab.
Increased Operational Complexity	This subnode collates data on references to when having paid staff in a community lab increases operational complexity.
Positive Implications	This subnode collates data that references the positive aspects of having paid staff as a part

Name	Description
	of a community lab's operations. This dissertation study found three main benefits of having paid staff at a community lab - Essential, Structured, and Well-Connected.
Essential	This subnode collates data that references how paid staff prioritize community lab activities as "essential" - top priority. This is in contrast to non-essential, where community lab tasks and obligations become non-essential in practice since volunteer activities are typically given low priority in peoples' obligations and tasks.
Formalized Oversight	This subnode collates data that references instances where community labs with paid staff show display instances of more formal oversight compared to volunteer-driven community labs. This includes having greater awareness of lab activities, dedicated personnel working on specific operations and issues, and other administrative and bureaucratic actions.
Payment for Services	This code collates all data that references paid staff as receiving funds due to a philosophy or interaction that emphasizes a payment for services.
Well-Connected	This subnode collates data that references how community labs with paid staff are well-connected to their local institutions. This relates to how these labs find ways to find the money and the resources to support paid staff (which, as noted, can contribute to high overhead).
Volunteer-Driven	This subnode collates data where community lab participants from leadership to members function as volunteers. Volunteers here refers to activities where people engage in community lab activities without financial compensation for the work that they do.

Name	Description
Negative Implications	This subnode compiles data on the negative implications of being a volunteer-driven organization. This dissertation found three main categories of negative implications for volunteer-driven organizations - Non-Essential, Undue Burden, and Shoestring Budget.
Accessibility Issues	This code collates references that discuss difficulties with accessing the lab in a volunteer-driven community lab context.
Closure	This code collates data that references closure of a community lab.
Disorganized Task Execution	This code collates references to where volunteer-driven efforts run into the issue of disorganized or poor execution of tasks and activities in community labs.
Exploitative	This code collates data that references potential tensions between volunteering and exploitation in a community lab context.
Instability	This code collates references to when volunteer-driven community labs and initiatives suffer from instability due to being a volunteer-driven effort.
Lowest Common Denominator - Expertise	This code collates references to when volunteer-driven organizations have trouble organizing due to wildly fluctuating expertise in participants.
Non-Essential	This subnode collates data on a negative implication of being volunteer-driven in community labs. Non-essential refers to how community lab operations and activities are never the top priority to individuals due to their volunteer nature. Therefore, people often have more pressing priorities than the work and operations at the community lab.
Shoestring Budget	This subnode collates data on references to low-resource and low-budget operations in volunteer-driven community labs.

Name	Description
Slow Progress	This code collates data that references how volunteer-led initiatives encounter slow progress in completing tasks.
Time Crunch	This code collates references to when volunteer-driven community labs experience time crunch or an insufficient amount of time/resources to accomplish goals and tasks.
Undue Burden	This subnode collates data on how volunteer-driven community labs may have experienced or may potentially experience undue burden in the community lab context. Undue burden refers to significant difficulty or expense on individuals to run tasks and operations in their community lab.
Positive Implications of Volunteer-Driven Community Labs	This subnode compiles data on positive sentiments and implications for operating community labs through a volunteer-driven participation model. This dissertation study found three main benefits from this participation model - Lower Overhead for Operations, Self-Motivation (compared to External Motivation), and Autonomy.
Autonomy	This subnode collates data on autonomy as a positive implication of being volunteer-driven. This differs from Self-Motivated where self-motivated indicates the drive to participate, as opposed to autonomy which highlights how people can operate independently in the community lab setting.
Lower Overhead for Operations	This subnode collates data to when people highlight how volunteer-driven community lab operations contributes to lower overhead for operations.
Mobilizing Groups of the Willing	This code collates data that references how volunteer organizations can rally and mobilize groups of willing participants in the community lab setting.
Organic Coordination	This code collates all references to how volunteer-driven organizations successfully

Name	Description
	develop agile/organic solutions in the face of competing priorities.
Self-Motivation	This subnode collates data on how people are self-motivated to do tasks and perform operations at community labs. This category is built on the observation that volunteer-driven organizations gather and are operated by people who want to be there, not those who have to be there.
Values	This subnode collates data that references the values or guiding ideology of community labs.
Community	This node codes for values that fall under the category of community. This includes Autonomy, Collaboration, Law-Abiding, Respect, and Safety.
Autonomy	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for autonomy - whether in their own actions or the actions of others.
Autonomy of the Individual	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for autonomy on an individual level - whether in their own actions or the actions of others.
Autonomy of the Lab	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for autonomy at the lab level - whether in their own actions or the actions of others.
Collaboration	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for collaboration - whether in their own actions or the actions of others.
Law-Abiding	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for following the law or

Name	Description
	promoting law-abiding practices - whether in their own actions or the actions of others.
Respect	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for respect - whether in their own actions or the actions of others.
Safety	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for safety - whether in their own actions or the actions of others.
Pushing Science Forward	This node codes for categories that indicate a value to push science forward. This includes Pushing Boundaries, Pro-Science, Transparency, Profit, Innovation, and Learning Through Failure.
Innovation	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for innovation - whether in their own actions or the actions of others.
Learning Through Failure	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for the necessity for failure - whether in their own actions or the actions of others.
Profit	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for profit - whether in their own actions or the actions of others.
Pro-Science	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for pro-science views - whether in their own actions or the actions of others.
Pushing Boundaries	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for pushing boundaries

Name	Description
	- whether in their own actions or the actions of others.
Transparency	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for transparency - whether in their own actions or the actions of others.
Social Justice and Equity	This node codes for data that are associated with values that have components of social justice and equity in them. This includes concepts like diversity, equity, sustainability, altruism, and active engagement.
Active Engagement	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for people being actively engaged in their community lab - whether in their own actions or the actions of others.
Altruism	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for altruism - whether in their own actions or the actions of others.
Diversity	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for diversity - whether in their own actions or the actions of others.
Diversity of Activities	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for a diversity of activities - whether in their own actions or the actions of others.
Diversity of Demographics	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for diversity of demographics - whether in their own actions or the actions of others.
Equity	This code refers to how individuals in field notes and/or interviews declare wording that

Name	Description
	indicates a desirability for equity - whether in their own actions or the actions of others.
Sustainability	This code refers to how individuals in field notes and/or interviews declare wording that indicates a desirability for sustainability - whether in their own actions or the actions of others.
Drive for Community Lab Participation	This node compiles data related to what motivates people to participate in community labs. Motivations can vary for many people, and understand these motivations is imperative to understanding some of the potential implications of community labs. There are two main subnodes associated with motivation - initial motivations (what brought a person to participate initially in a community lab) and current motivations the motivations that participants (longer than 6 months) have for continuing to participate.
Current Motivation	This subnode collates data related to the current motivations that drive longer-term members (greater than 6 months) in community labs to continue participating. This subnode helps not only understand existing motivations for community lab participation, but also provides insight into how motivations may change over time and participation.
Access to Capabilities	This capability node collates sub-nodes that all express how founders were inspired to found community labs due to a desire to increase access to scientific capabilities in unconventional spaces.
Desire to Start a Project	This subnode collates data on how an individual's desire to start their own project may be a current motivation for long term participants in community labs.

Name	Description
Expertise	This subnode collates data that references expertise as one of the reasons why people initially chose to join a community lab.
Interest in a Specific Project	This subnode collates data related to how long-term members may participate in a community lab due to a specific project that they learn is either hosted at the community lab or that a community lab participates in.
Lab Availability	This subnode collects data related to how the availability of a lab outside of traditional academia, industry, and government may be a current motivation for long-term participants in a community lab.
Professional Interest	This node collates data that references professional interests as a current factor for participating in a community lab.
Community	This node collates all subnodes that indicate founders were driven to start a community lab to spread, build on, and further develop or create the DIYBio community.
Alignment of Values	This subnode collects data on how harmony and alignment of a person's individual values to those of community labs may be a current motivation factor for community lab participation. Key concepts include increasing accessibility of science knowledge and tools, empowering citizens to tinker and engage in science, and biotech innovation in unconventional spaces.
Community Culture	This subnode collates data that references elements of community culture.
Community Service	This subnode collects data related to directly becoming involved in community initiatives as a current motivation for long-term participants in community labs. Please note that this is distinct from "Social Interaction for Fun", which is a subnode that collects data related to social interactions and the desire to participate and become part of a group as a current

Name	Description
	motivation for long-term people participating in community labs.
Passion for Building	This subnode collates data that references a passion or need for hands-on building as a current motivation for participating in a community lab.
Passion for Learning	This subnode collates data that references a passion for learning as an initial motivation for participating in a community lab.
Passion for Science	This subnode collects data related to long-term members indicating a passion for science as a current motivation to continue participating in a community lab.
Passion for Teaching	This subnode collects data related to long-term members indicating a passion for teaching as a current motivation to continue participating in a community lab.
Social Interaction for Fun	This subnode collects data related to social interaction and the desire to participate and become part of a group as a current motivation for long-term participants in community labs. Please note that this is distinct from "Community Service". "Community Service" is a subnode that collects data related to directly becoming involved in community initiatives as a current motivation for long-term participants in community labs.
Transformative Change	This node collates sub-nodes where the founder expressed a drive to found a community lab because of a desire to effect transformative change.
Alternative to Traditional Science Spaces	This subnode collates data that references community labs as an alternative to traditional science spaces as a current motivation for why people get involved in community labs.
Novel	This subnode collates data for how novelty (the quality of community labs as being new, unusual, or original) may be a current

Name	Description
	motivation for long-term participants in community labs.
Founding Motivations	This subnode collates data that is specific to founders only (founders of community labs) - This node collates data that references what motivated founders to found community lab spaces.
Access to Capability	This capability node collates sub-nodes that all express how founders were inspired to found community labs due to a desire to increase access to scientific capabilities in unconventional spaces.
Geographic Preference	This code collates references where founders indicate that a geographically preferred alternative was one of the reasons why they founded a community lab.
Pooling Knowledge, Expertise	This code collates references to founders stating that their motivations were to pool knowledge and expertise - facilitate a learning environment in an unconventional space.
SciComm or SciEd	This code compiles all references to when a founder's motivation deals with science communication or education.
Community	This node collates all subnodes that indicate founders were driven to start a community lab to spread, build on, and further develop or create the DIYBio community.
Community Building	This code collates all references to the presence or building of a community as a founding motivation for a founder building a community lab.
Inspired by Other Labs	This code compiles all references to when founders were inspired by other community labs opening - serving as a motivation to open their own community lab.
Passion for Science	This code collates all references to a founder's motivation for starting a community lab being a passion for science.

Name	Description
Transformative Change	This node collates sub-nodes where the founder expressed a drive to found a community lab because of a desire to effect transformative change.
Demystifying Science	This code collates all references to founders' motivations involving a desire to demystify science as a reason for founding a community lab.
Unmet Needs in Institutions	This code compiles all references to when the data indicates that traditional infrastructures did not meet the needs of participants in the DIYBio community lab movement.
Initial Motivations for Participating in a Community Lab	This subnode compiles data on motivations that initially led members to participate in community lab spaces.
Access to Capabilities	This capability node collates sub-nodes that all express how founders were inspired to found community labs due to a desire to increase access to scientific capabilities in unconventional spaces.
Desire to Start a Project	This subnode collates data on how an individual's desire to start their own project may be an initial motivation to join a community lab.
Expertise	This subnode collates data that references expertise as one of the reasons why people initially chose to join a community lab.
Geographic Proximity	This code collates all instances where people reference geographic proximity as a motivation to participating in a community lab.
Interest in a Specific Project	This subnode collates data related to how new members may initially join a community lab due to a specific project that they learn is either hosted at the community lab or that a community lab participates in.
Lab Availability	This subnode collects data related to how the availability of a lab outside of traditional

Name	Description
	academia, industry, and government may have been the initial motivation to draw someone into a community lab.
Professional Interest	This node collates data that references professional interests as a driving factor for initially participating in a community lab.
Community	This node collates all subnodes that indicate founders were driven to start a community lab to spread, build on, and further develop or create the DIYBio community.
Alignment of Values	This subnode collects data on how harmony and alignment of a person's individual values to those of community labs may be an initial motivation factor for community lab participation. Key concepts include increasing accessibility of science knowledge and tools, empowering citizens to tinker and engage in science, and biotech innovation in unconventional spaces.
Community Culture	This subnode collates data that references elements of community culture.
Community Service	This subnode collects data related to directly becoming involved in community initiatives as an initial motivation for people participating in community labs. Please note that this is distinct from "Social Interaction for Fun", which is a subnode that collects data related to social interactions and the desire to participate and become part of a group as an initial motivation for people participating in community labs.
Passion for Building	This subnode collates data that references a passion or need for hands-on building as an initial motivation for participating in a community lab.
Passion for Learning	This subnode collates data that references a passion for learning as an initial motivation for participating in a community lab.

Name	Description
Passion for Science	This subnode collects data related to members indicating a passion for science as an initial motivation to joining a community lab.
Passion for Teaching	This subnode collects data related to members indicating a passion for teaching as an initial motivation to joining a community lab.
Social Interaction for Fun	This subnode collects data related to social interaction and the desire to participate and become part of a group as an initial motivation for people participating in community labs. Please note that this is distinct from "Community Service". "Community Service" is a subnode that collects data related to directly becoming involved in community initiatives as a potential motivation for people participating in community labs.
Transformative Change	This node collates sub-nodes where the founder expressed a drive to found a community lab because of a desire to effect transformative change.
Alternative to Traditional Science Spaces	This subnode collates data that references community labs as an alternative to traditional science spaces as an initial motivation for why people get involved in community labs.
Novel	This subnode collates data for how novelty (the quality of community labs as being new, unusual, or original) was an initial motivation for people to join a community lab.
Knowledge Transfer in Community Labs	This node collates data that references how knowledge transfer occurs in the community lab setting. This dissertation studied the knowledge transfer of tacit knowledge - knowledge and abilities that can be passed between individuals by personal contact but cannot, or has not been, passed through means that are easily articulated, codified, stored, or accessed.
Means of Knowledge Transfer	This subnode collates data that references how community lab members transfer knowledge

Name	Description
	and skills to others. This dissertation found two main dynamics associated with knowledge transfer: the traditional dynamic of expert to amateur interactions, but also a novel dynamic of trained amateur to naive amateur interactions.
Expert to Amateur Interactions	This subnode collates data that references how experts interacted with amateurs to transfer knowledge. This study pulled from tacit knowledge literature to look at two main considerations for expert-amateur interactions. One is the ratio between expert to amateur, and the other is the type of interactions (both in-person and through digital means) expert-amateur interactions encompass.
Expect to Amateur Ratio	This subnode collates data that references incidents that highlight the number of experts initiating knowledge transfer compared to the number of amateurs engaged in the knowledge transfer. These ratios include 1:1, 1:2, 1:3, or 1:4 or Greater.
1 to 1	This subnode collates data that references knowledge transfer interactions between experts and amateurs where the expert to amateur ratio was 1:1.
1 to 2	This subnode collates data that references knowledge transfer interactions between experts and amateurs where the expert to amateur ratio was 1:2.
1 to 3	This subnode collates data that references knowledge transfer interactions between experts and amateurs where the expert to amateur ratio was 1:3.
1 to 4 or Greater	This subnode collates data that references knowledge transfer interactions between experts and amateurs where the expert to amateur ratio was 1:4 or Greater.
Type of Interaction	This subnode collates data that references the types of interactions that occur between

Name	Description
	experts and amateurs during knowledge transfer. This study found 2 main settings that experts interacted with amateurs: in-person and through digital transfer.
Digital Transfer	This subnode collates data that references digital resources for knowledge transfer use. Digital resources, such as videos, consultations, and other resources created by experts are readily accessible through the internet. Scholars argue that these digital resources enable broader and easier transfer of tacit knowledge.
Conversation	This subnode collates data that references situations where knowledge transfer was initiated between experts and amateurs in the form of digital conversation, where the expert and amateur engage in two-way conversation to further elaborate, clarify, and explore the discussed topic. This differs from an explanation, where the transfer from expert to amateur is one-sided.
Explanation	This subnode collates data that references situations where knowledge transfer was initiated between experts and amateurs in the form of a digital explanation. An explanation is a one-sided information transfer where the expert communicates information to the amateur. This differs from a conversation, where the expert and amateur engage in digital two-way conversation to further elaborate, clarify, and explore the discussed topic.
Hands-On Demonstration	This subnode collates data that references hands-on demonstration of a lab skill, a technique, or other knowledge transfer activity that is facilitated through a hands-on demonstration from an expert to an amateur. This differs from a visual demonstration, where the amateur just watches the expert perform a knowledge transfer object of interest. This also differs from shadowing,

Name	Description
	where an amateur follows an expert across more than one specific skills, technique, or other object of knowledge transfer.
Monitoring	This subnode collates data that references monitoring as a type of information between experts and amateurs to allow tacit knowledge transfer. Monitoring is when the expert is present in the lab to observe and check the quality of work and the progress of an amateur they are training.
Practice	This subnode collates data that references when amateurs practice, whether in the presence or not of the expert. This differs from a hands-on demonstration in that a hands-on demonstration is understood as a one-off that requires the presence of the expert, while practice can be self-motivated by the amateur to gain more hands-on experience with a technique, a lab skill, or other object of knowledge transfer.
Shadowing	This subnode collates data that references an amateur shadowing an expert to learn or gain insight into a technique or other knowledge transfer activity. Shadowing refers to following and observing an expert. This differs from a visual demonstration, where the amateur just watches the expert perform a knowledge transfer object of interest. This also differs from hands-on demonstrations, where the expert has the amateur gain hands-on experience of the object of knowledge transfer.
Visual Demonstration	This subnode collates data that references visual demonstration of a lab skill, a technique, or other knowledge transfer activity that can be facilitated through a visual demonstration from an expert to an amateur. This differs from a hands-on demonstration, where the amateur actively participates and experiences the knowledge being transferred. This also differs from shadowing, where an

Name	Description
	amateur follows an expert across more than one specific skills, technique, or other object of knowledge transfer.
In-Person	This subnode collates data that references knowledge transfer activities that happen in-person. Tacit knowledge is academically discussed as knowledge that requires one-to-one, close contact, and hands-on learning methods to successfully transfer knowledge that is difficult to communicate from expert to amateur.
Conversation	This subnode collates data that references situations where knowledge transfer was initiated between experts and amateurs in the form of conversation, where the expert and amateur engage in two-way conversation to further elaborate, clarify, and explore the discussed topic. This differs from an explanation, where the transfer from expert to amateur is one-sided.
Explanation	This subnode collates data that references situations where knowledge transfer was initiated between experts and amateurs in the form of an explanation. An explanation is a one-sided information transfer where the expert communicates information to the amateur. This differs from a conversation, where the expert and amateur engage in two-way conversation to further elaborate, clarify, and explore the discussed topic.
Hands-On Demonstration	This subnode collates data that references hands-on demonstration of a lab skill, a technique, or other knowledge transfer activity that is facilitated through a hands-on demonstration from an expert to an amateur. This differs from a visual demonstration, where the amateur just watches the expert perform a knowledge transfer object of interest. This also differs from shadowing, where an amateur follows an expert across

Name	Description
	more than one specific skills, technique, or other object of knowledge transfer.
Monitoring	This subnode collates data that references monitoring as a type of information between experts and amateurs to allow tacit knowledge transfer. Monitoring is when the expert is present in the lab to observe and check the quality of work and the progress of an amateur they are training.
Practice	This subnode collates data that references when amateurs practice, whether in the presence or not of the expert. This differs from a hands-on demonstration in that a hands-on demonstration is understood as a one-off that requires the presence of the expert, while practice can be self-motivated by the amateur to gain more hands-on experience with a technique, a lab skill, or other object of knowledge transfer.
Shadowing	This subnode collates data that references an amateur shadowing an expert to learn or gain insight into a technique or other knowledge transfer activity. Shadowing refers to following and observing an expert. This differs from a visual demonstration, where the amateur just watches the expert perform a knowledge transfer object of interest. This also differs from hands-on demonstrations, where the expert has the amateur gain hands-on experience of the object of knowledge transfer.
Visual Demonstration	This subnode collates data that references visual demonstration of a lab skill, a technique, or other knowledge transfer activity that can be facilitated through a visual demonstration from an expert to an amateur. This differs from a hands-on demonstration, where the amateur actively participates and experiences the knowledge being transferred. This also differs from shadowing, where an amateur follows an expert across more than

Name	Description
	one specific skills, technique, or other object of knowledge transfer.
Structure	This subnode collates data that references the organizational factors that play a role in tacit knowledge transfer in the community lab context. This study saw two main areas where tacit knowledge transfers occurred: during projects and during formal lab skills classes.
Lab Skills Classes	This subnode collates data that references organizational factors related to tacit knowledge that were observed during structured offerings from community labs that explicitly taught lab skills and techniques. This dissertation study observed four main organizational factors that related to tacit knowledge in this context: preparation, expertise, format, and obstacles.
Expertise	This subnode collates data that references expertise within a lab skills class setting.
Format	This subnode collates references to how lab skills classes are formatted to teach naive amateurs and interested parties laboratory techniques and skills.
Obstacles	This subnode collates data that references obstacles and issues that arise in preparing, executing, and follow-up for lab skills classes.
Preparation	This subnode collates data that references advanced preparation for lab skills classes.
Projects	This subnode collates data the references organizational factors salient to tacit knowledge transfer observed during community lab projects: individual or collaborative ventures with a specific purpose or aim. This dissertation study found 5 organizational factors associated with projects: funding, expertise, management, stability, and obstacles.

Name	Description
Expertise	This subnode collates data that references expertise present in a project setting.
Funding	This subnode collates data that references financial funding and resources to implement a project.
Management	This subnode collates data that references how projects are managed, including leadership of projects, autonomy of members, and other elements.
Obstacles	This subnode collates data that references obstacles to the successful completion of a project or making progress on a project.
Stability	This subnode collates data that references stability - consistency of effort, consistency of expectations, and consistency of members in a project context.
Tasks	This code collates all data that references tasks associated with projects done in a community lab setting.
Trained Amateur to Naive Amateur Interactions	This subnode collates data that references interactions between trained amateurs and native amateurs in knowledge transfer activities. This dissertation looked at two main areas on trained amateur - naive amateur interactions - The trained-amateur to naive amateur ratio when knowledge transfer occurred, and the in-person and digital type of instruction that occurred during knowledge transfer.
Trained Amateur to Naive Amateur Ratio	
1 to 1	This subnode collates data that references knowledge transfer interactions between trained amateurs and naive amateurs where the trained to naive amateur ratio was 1:1.
1 to 2	This subnode collates data that references knowledge transfer interactions between

Name	Description
	trained amateurs and naive amateurs where the trained to naive amateur ratio was 1:2.
1 to 3	This subnode collates data that references knowledge transfer interactions between trained amateurs and naive amateurs where the trained to naive amateur ratio was 1:3.
1 to 4 or Greater	This subnode collates data that references knowledge transfer interactions between trained amateurs and naive amateurs where the trained to naive amateur ratio was 1:4 or Greater.
Type of Interaction	This subnode collates data that references the types of interactions that occur between trained amateurs and naive amateurs during knowledge transfer. This study found 2 main settings that trained amateurs interacted with naive amateurs: in-person and through digital transfer.
Digital Transfer	This subnode collates data that references digital resources for knowledge transfer use. Digital resources, such as videos, consultations, and other resources created by trained amateurs are readily accessible through the internet. Scholars argue that these digital resources enable broader and easier transfer of tacit knowledge.
Conversation	This subnode collates data that references situations where knowledge transfer was initiated between trained amateurs and naive amateurs in the form of digital conversation, where the trained and naive amateurs engage in two-way conversation to further elaborate, clarify, and explore the discussed topic. This differs from an explanation, where the transfer from expert to amateur is one-sided.
Explanation	This subnode collates data that references situations where knowledge transfer was initiated between trained amateurs and naive amateurs in the form of a digital explanation.

Name		Description
		An explanation is a one-sided information transfer where the trained amateur communicates information to the naive amateur. This differs from a conversation, where the expert and amateur engage in digital two-way conversation to further elaborate, clarify, and explore the discussed topic.
	Hands-On Demonstration	This subnode collates data that references hands-on demonstration of a lab skill, a technique, or other knowledge transfer activity from a trained amateur to a naive amateur. This differs from a visual demonstration, where the naive amateur just watches the trained amateur perform a knowledge transfer object of interest. This also differs from shadowing, where the trained amateur is followed by the naive amateur across more than one specific skills, technique, or other object of knowledge transfer.
	Monitoring	This subnode collates data that references digital monitoring as a type of information between trained amateurs and naive amateurs to allow tacit knowledge transfer. Digital monitoring is when the trained amateur is digitally present in the lab (through a voice call or digital video conference) to observe and check the quality of work and the progress of an amateur they are training.
	Practice	This subnode collates data that references when amateurs practices, whether in the presence or not of the trained amateur. This differs from a hands-on demonstration in that a hands-on demonstration is understood as a one-off that requires the presence of the trained amateur, while practice can be self-motivated by the naive amateur to gain more hands-on experience with a technique, a lab skill, or other object of knowledge transfer.
	Shadowing	This subnode collates data that references a naive amateur shadowing a trained amateur to

Name	Description
	learn or gain insight into a technique or other knowledge transfer activity. Shadowing refers to following and observing a trained amateur.
Visual Demonstration	This subnode collates data that references digital visual demonstration of a lab skill, technique, or other knowledge transfer activity that can be facilitated through a visual demonstration from a trained to naive amateur.
In-Person	This subnode collates data that references knowledge transfer activities that happen in-person. Tacit knowledge is academically discussed as knowledge that requires one-to-one, close contact, and hands-on learning methods to successfully transfer knowledge that is difficult to communicate from expert to amateur.
Conversation	This subnode collates data that references situations where knowledge transfer was initiated between trained amateurs and naive amateurs in the form of conversation, where the trained and naive amateur engage in two-way conversation to further elaborate, clarify, and explore the discussed topic. This differs from an explanation, where the transfer from trained to naive amateur is one-sided.
Explanation	This subnode collates data that references situations where knowledge transfer was initiated between trained and naive amateurs in the form of an explanation. An explanation is a one-sided information transfer where the trained amateur communicates information to the naive amateur.
Hands-On Demonstration	This subnode collates data that references hands-on demonstration of a lab skill, a technique, or other knowledge transfer activity that is facilitated through a hands-on demonstration from trained to naive amateurs.
Monitoring	This subnode collates data that references monitoring as a type of information between

Name	Description
	trained amateurs and naive amateurs to allow tacit knowledge transfer. Monitoring is when the trained expert is present in the lab to observe and check the quality of work and the progress of a naive amateur they are training.
Practice	This subnode collates data that references when naive amateurs practice, whether in the presence or not of the trained amateur. This differs from a hands-on demonstration in that a hands-on demonstration is understood as a one-off that requires the presence of the trained amateur, while practice can be self-motivated by the naive amateur to gain more hands-on experience with a technique, a lab skill, or other object of knowledge transfer.
Shadowing	This subnode collates data that references a naive amateur shadowing a trained amateur to learn or gain insight into a technique or other knowledge transfer activity. Shadowing refers to following and observing a trained amateur.
Visual Demonstration	This subnode collates data that references visual demonstration of a lab skill, a technique, or other knowledge transfer activity that can be facilitated through a visual demonstration from a trained amateur to a naive amateur.
Learning about Community Labs	This node compiles data on how people learn about a community lab. This study found 5 typical ways that people learned about community labs: online community lab messaging, in-person community lab messaging, professional connections, interpersonal connections, and serendipity.
In-Person Community Lab Messaging	This subnode includes in-person encounters with the community lab itself or its materials, including brochures, pamphlets, flyers, and lab-represented events.
Interpersonal Connections	This subnode compiles data on people that learned of community labs initially through

Name	Description
	friends, family, and connections of other close acquaintances.
Online Community Lab Messaging	This subnode includes learning about community labs through online social media, group and activity websites, the lab's personal site, and other predominantly online means of discovery.
Professional Connections	This subnode compiles data on people that learned of community labs initially through professional connections.
Serendipity	This subnode compiles data on instances where individuals initially learn of community labs unintentionally - instances where people may not have deliberately learned about community labs, but learned about them in the process of doing something else.

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